APPLICATIONS SEMINAR A4

SID 2001
San Jose, California, June 6, 2001

FLAT PANEL DISPLAY MEASUREMENTS AND STANDARDS

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Summary

Display metrology is discussed as applied to flat panel displays (FPDs). Topics include the importance of proper set up, expected measurement uncertainty vs. repeatability, and problems in making accurate light measurements. The role played by measurement diagnostics is considered and encouragement is given to employ such diagnostics routinely. A review of the status of international display standards is provided.

SOCIETY FOR INFORMATION DISPLAY

* *Electricity Division, Electronics and Electrical Engineering Laboratory, Technology Administration, U.S. Department of Commerce.*

Flat Panel Display Measurements and Standards

Because of the explosive growth of the demand for electronic displays and competition within the display industry, there is an increasing need for well-defined display metrology. Good metrology is needed to level the playing field, so to speak, not only within a particular display technology, but also across technologies. For example, we want to be able to compare the contrast of one display with the contrast of another display in a meaningful way and not wonder how the measurement was made. The parameters that characterize the display should not depend upon who measures the display (to within the limits of the uncertainty of the measurements). Those who incorporate displays into their equipment need to be able to specify what they want in such a manner that there will be no argument as to whether a display meets the specifications or not. Nobody wants surprises, and companies that do a good job of manufacturing should have the metrological backing to prove the quality of their products. All these concerns require unambiguous metrology. In this seminar, we discuss several aspects of display metrology. We then provide a list of many of the associated standards activities for your further reference.

Display Metrology

Characterization of the display depends upon how the display is configured. How the display is configured depends upon the task for which it is to be used. How well the measurements are made depends upon how well the measurements *can* be made in addition to the methods, equipment, and skills employed. Good metrology depends upon a realistic expectation of the instrumentation performance, a sensitivity to diagnostics, and an understanding of the limits of the measurement apparatus.

Display Standards

Display standards can contain several categories of specifications. They can specify what to measure, how to measure, how to check or correct the measurement, and the compliance limits of acceptability of a measurement result. Many standards concern themselves with having displays meet a certain minimum of performance. These are performance or compliance standards, and they often must deal with ergonomic and psychophysical results to set the criteria of acceptance. Often standards avoid a thorough discussion of how to measure parameters and how to establish a confidence in the measurement result. In the following pages we provide a partial listing and contact information for display standards and related activities.

Disclaimer:

STANDARDS ACTIVITIES

AAPM — American Association of Physicists in Medicine

Task Group 18: Acceptance Testing and Quality Control of Electronic Display Devices for Soft-copy Display of Medical Images

Chair: Ehsan Samei, PhD, M.E., Assistant Professor of Radiology, Duke University Medical Center, DUMC 3302, Durham, NC 27710, Voice: 919-684-7852 Fax: 919-684-7122, E-mail: samei@duke.edu

ANSI — American National Standards Institute

http://www.ansi.org/

ANSI HFES-100

Human Factors and Ergonomics Society (HFES)

Robert J. Beaton, Ph.D., CPE, Displays and Controls Laboratory, Industrial and Systems Engineering (0118), 549 Whittemore Hall, Virginia Tech, Blacksburg, VA 24060, USA, Phone: 540-231-5936, Fax: 540-231-3322, E-mail: bobb@vt.edu, Web: Office: http://bobb.dcl.vt.edu, Lab: http://www.dcl.vt.edu

ANSI Projection Standards IT7.227 and IT7.228

Photographic and Imaging Manufacturers Association, Inc. (PIMA) IT-7 Committee

Leon Shapiro, Chairman, NIDL, (609) 734-2527, lshapiro@sarnoff.com

Some other standards and guides that may be of interest:

ANSI/SAE ARP 1782 Photometric and Colorimetric Measurement Procedures for Airborne Direct View CRT Displays

ANSI/SAE ARP 4102 Flight Deck Panels, Controls, and Displays (core document)

ANSI/SAE ARP 4102/7 Electronic Displays

ANSI/SAE ARP 4102/8 Flight Deck, Head-Up Displays

ANSI/SAE ARP 4032 Human Engineering Considerations in the Application of Color to Electronic Aircraft Displays

ANSI/SAE AS 8034 (R1989) Minimum Performance Standard for Airborne Multipurpose Electronic Displays

ANSI/SAE ARP 1068A Flight Deck Instrumentation, Display Criteria, and Associated Controls for Transport Aircraft

SAE ARP 1068B Flight Deck Instrumentation, Display Criteria and Associated Controls

ANSI/SAE ARP 1874 Design Objectives for CRT Displays for Part 25 (Transport) Aircraft

ANSI/SAE ARP 4067 Design Objectives for CRT Displays for Part 23 Aircraft

ANSI/SAE ARP 571C Flight Deck Controls and Displays for Communication and Navigation Equipment for Transport Aircraft

ANSI/SAE ARP 4155 Human Interface Design Methodology for Integrated Display Symbology

ANSI/NCSL Z540-2-1997 *U.S. Guide to the Expression of Uncertainty in Measurement*, (American National Standards Institute/National Conference of Standards Laboratories), first edition, October 9, 1997.

ASTM — American Society for Testing and Materials

http://www.ansi.org/

Publications of interest:

ASTM Standards on Color and Appearance Measurement, Fifth edition, 1996. Sponsored by Committee E-12 on Appearance. This is a wonderful reference to have.

E284-95a Standard Terminology of Appearance

E1392-90 Standard Practice for Angle Resolved Optical Scatter measurements on Specular or Diffuse Surfaces.

There are some newer versions available:

ASTM E1455-96a Obtaining Colorimetric Data from a Visual Display Unit Using Tristimulus Colorimeters

ASTM E1336-96 Obtaining Colorimetric Data From a Visual Display Unit by Spectroradiometry

ASTM E1682-96 Modeling the Colorimetric Unit Properties of a Visual Display

CIE — Commission Internationale de l'Eclairage

(International Commission on Illumination)

http://www.cie.co.at/cie/

CIE Division 2 Physical Measurement of Light and Radiation

Teresa Goodman, Director. Yoshi Ohno, Secretary

CIE Division 2 Web: http://nml.csir.co.za/~cie2

CIE Div.2 TC2-42 Colorimetry of Displays

Andrew R. Hanson, Chair; contact Christine Wall at NPL (Christine.Wall@npl.co.uk) for more information.

CIE Division 8 Image Technology

Todd Newman, Director. Web: http://www.colour.org

Publications of interest:

CIE Publication 15.2: Colorimetry, 2nd ed. (1986)

CIE Publication 17.4, International Lighting Vocabulary (1989)

CIE Publication No. 44, Absolute Methods for Reflection Measurement

CIE Publication No. 46, A Review of Publications on Properties and Reflection Values of Material Reflection Standards

CIE Publication No. 69, Methods of Characterizing Illuminance and Luminance Meters

CIE Publication 122 The Relationship Between Digital and Colorimetric Data for Computer-Controlled CRT Displays (1996)

CORM — Council for Optical Radiation Measurements
http://www.corm.org

CORM CR-5 Electronic Display
Steve Brown, Chair

EIA — Electronic Industries Association
http://www.eia.org/eng/default.htm

EIA JT-6 Committee on Color CRTs
Harry Swank, Chair, Thomson Consumer Electronics
1002 New Holland Ave., Lancaster, PA 17601
Phone: 717-295-2858, Fax: 717-295-6092, E-mail: swankh@tce.com

EIA JT-31 Committee on Optical Characteristics of Display Devices
George Ehemann, Chair, Thomson Consumer Electronics, 1002 New Holland Ave., Lancaster, PA 17601, Phone: 717-295-6216, Fax: 717-295-6092, E-mail: ehemanng@tce.com (Note: Standards previously within the purview of the inactive JT-20 committee have been transferred to JT-31).

Here are some older CRT documents:
EIA TEP105 Series:
- TEP-11-B "Color Measurement and White Set-Up Procedure for CRT Screens" (June 2000).
- TEP105-16-A "Test Method for Phosphor Linearity" (June 2000).
- TEP105-14 "Measurement of Phosphor Persistence of CRT Screens" (April 1987). The alternate pulsed raster method in Appendix II of that document had proven to be very useful to phosphor vendors in the late 1980s for registering persistence data. Prior to the issuing of TEP105-14 a very tedious and less accurate method of numerical integration of the impulse response had been used. EIAJ document ED-2102, "Measuring Methods of Phosphor Persistence of CRT Screens", dated 1988, gives reference (and preference) to the pulsed raster procedure introduced in TEP-105-14.

TEP116-C Optical Characteristics of Cathode Ray Tube Screens (Feb., 1993)
EIA TEB25 A Survey Of Data-Display CRT Resolution Measurement Techniques (June, 1985)
EIA TEP192 Glossary of Cathode-Ray Tube Terms and Definitions (Sept., 1984)
EIA TEB27 Relating Display Resolution and Addressability (Sept., 1988)
EIA TEB 24 Effect of Pulse Shape in Raster Dot Alpha-Numeric CRT Presentation on Spot Luminance and Luminance Distribution

EIAJ — Electronic Industries Association of Japan
Measuring Methods for Matrix Liquid Crystal Display Modules
See: www.eiaj.or.jp

IEC — International Electrotechnical Committee

http://www.iec.ch/

IEC/TC 100 Audio, Video and Multimedia Systems and Equipment

SC100C together with its WG6 have been disbanded. Instead of them IEC/TC100 has introduced a new scheme, Technical Areas (TA) to which major projects under SC 100C have been moved. Other projects such as Project 61947 are now moved to project teams (PT) directly under IEC/TC100.

PT 61947 Electronic Projection (61947-1: Variable Resolution Projector; 61947-2: Fixed Resolution Projector)

Leon Shapiro, Project Leader, Sarnoff Corporation, (609) 734-2527, lshapiro@sarnoff.com

TA 2: Colour Measurement and Management

TA-manager (TAM) is Hiroaki Ikeda

Technical Secretary (TS) is Theo Laans

IEC 61966 Colour Measurement and Management in Multimedia Systems and Equipment

Hiroaki Ikeda, Convener/Project leader, Chiba University

E-mail: ikeda@hike.te.chiba-u.ac.jp

Web: http://w3.hike.te.chiba-u.ac.jp/IEC/100/PT61966

Regarding IEC 61966-4: Multimedia systems and equipment - Colour measurement and management - Part 4: Equipment using liquid crystal display panels has been published as International Standard, which will be purchased from IEC Central Office in Geneva (Edition 1, Bilingual, 75 pp, CHF 123). IEC/FDIS 61966-5: PDP will soon be voted upon.

TA 3: Infrared systems

TA 4: Digital system interfaces

IEEE — Institute of Electrical and Electronics Engineers

www.ieee.org

IEEE 1140-1994 IEEE Standard for the Measurement of Electric and Magnetic Fields from Video Display Terminals (VDT) from 5 Hz to 400 kHz

ISO — International Organization for Standardization

United States Technical Advisory Group to the ISO Subcommittee for Ergonomics of Human System Interaction, Jim Williams, Chair US TAG to ISO/TC159/SC4, Telcordia Technologies, Piscataway, NJ, phone 732-699-5491, fax 732-336-2605, ergojim@earthlink.net

http://www.iso.ch/

If it is difficult to connect to above site, try: http://133.82.181.177/ikeda/ISO/home.html

ISO documents are ordered through the member bodies for each participating country. For example, in the USA people would use ANSI (American National Standards Institute), 11

West 42nd Street, 13th floor, New York, N.Y. 10036, Telephone: + 1 212 642 49 00, Telefax: + 1 212 398 00 23, Internet: info@ansi.org.

ISO 13406 Part 2: "Ergonomic Requirements for the Use of Flat Panel Displays," ISO/TC 159/SC 4/WG 2, to be published (becoming a FDIS at the time of this writing. By the time of this seminar the FDIS should have been accepted and in the process of issuing as International standard. The standard should be available from ISO and national standard bodies by the end of year 2000, possibly earlier.).

ISO 9241 series: Ergonomic requirements for office work with visual display terminals (VDTs). Contact ISO: www.iso.ch/infoe/guide.html for specific ordering information. Here are the three of interest to display metrologists (TC 159 / SC 4):

***ISO 9241 Part 3* –** Visual display requirements
ISO 9241 Part 7 – Requirements for display with reflection
***ISO 9241 Part 8* –** Requirements for displayed colours.

NOTE: The revision of ISO 13406 and ISO 9241-3, -7, -8 has started early in the year 2000. The new standard will be called: ISO 18789 Ergonomics of human system-interaction - Ergonomic requirements and measurement techniques for electronic visual displays. In this standard the metrology will be separated from the ergonomics requirements, so as to be practical to different types of users of the standard.

IEC TC100 standardizes aspects of displays related to display of multimedia. These standards focus on requirements of those aspects that affect the color quality of the display. Some of these standards are close to publication.

IEC TC42 standardizes aspects of flat panels displays at the component level. It will take some time until we see the first publicly available draft.

The following may be of some interest:

ISO 8341:1989 Photography, Slide projectors and filmstrip projectors -- Illumination test.

ISO 9767:1990 Photography, Overhead projectors -- Methods for measuring and reporting performance characteristics.

ISO 11314:1995 Photography, Projectors -- Image size/projection distance calculations.

ISO 2910:1990 Cinematography, Screen luminance for the projection of motion-picture prints in indoor theatres and review rooms.

ISO 12608:1996 Cinematography, Room and surround conditions for evaluating television display from telecine reproduction.

Publication of interest:

ISO *Guide to the Expression of Uncertainty in Measurement,* (International Organization for Standardization), 1995.

NIDL — National Information Display Laboratory

NIDL Publication No. 171795-036, Display Monitor Measurement Methods
Under discussion by EIA Committee JT-20.
Part 1: Monochrome CRT Monitor Performance, Draft Version 2.0, July 12, 1995. NIDL Publication No. 171795-037, Display Monitor Measurement Methods under Discussion by EIA (Electronic Industries Association) Committee JT-20.
Part 2: Color CRT Monitor Performance, Draft Version 2.0, July 12, 1995.

SAE — Society of Automotive Engineers

400 Commonwealth Dr., Warrendale, PA 15096-0001
http://www.sae.org/PRODSERV/STANDARD/standard.htm

ARP4260 — Photometric and Colorimetric Measurement Procedures for Airborne Flat Panel Displays.
Subcommittee of the SAE A-20 Aircraft Lighting Committee
http://www.sae.org/PRODSERV/STANDARD/standard.htm

SAE J 1757 Standard Metrology for Vehicular FPDs.
Silviu Pala, Chair, silviu_pala@denso-diam.com.
A Discussion Forum on Vehicular Flat Panel Display Metrology is available at the SAE web site above. This group is working with the ISO TC22 SC13 WG8 task force on DIS 15008 "Road Vehicles - Ergonomics Applicable to Road Vehicles - Display Legibility Standard". The ISO chair is Rudi Haller, rudolf.haller@bmw.de.
SAE J1757-1 Optical Performance
SAE J1757-2 Electrical Performance
SAE J1757-3 Environmental Performance
(SAE J1757-1 is in the committee voting stage)

SMPTE — Society of Motion Picture and Television Engineers

595 W. Hartsdale Ave., White Plains, NY 10607-1824 U.S.A,
tel: +1 914 761 1100 / fax: +1 914 761 3115, e-mail: smpte@smpte.org
Web: http://www.smpte.org/

SMPTE Standard 170M-1994 "Television – Composite Analog Video Signal – NTSC for Studio Applications"

Other SMPTE standards that may be of interest:
SMPTE RP 12-1997 Screen Luminance for Drive-In Theaters
SMPTE RP 185-1995 Classification of Projection Depth of Focus
SMPTE RP 167-1995 Alignment of NTSC Color Picture Monitors
SMPTE RP 145-1994 SMPTE C Color Monitor Colorimetry
SMPTE RP 166-1995 Critical Viewing Conditions for Evaluation of Color Television Pictures
SMPTE RP 27.1-1989 Specification for Operational Alignment Test Pattern for Television
SMPTE RP 38.1-1989 Specifications for Deflection Linearity Test Pattern for Television
SMPTE RP 27.5-1989 Specifications for Mid-Frequency Response Test Patterns for Television

SMPTE RP 133-1991 Specifications for Medical Diagnostic Imaging Test Patterns for Television Monitors and Hard Copy Recording Cameras
SMPTE RP 94-1993 Gain Determination of Front Projection Screens
SMPTE RP 95-1994 Installation of Gain Screens
SMPTE 196M-1995 Motion -Picture Film -Indoor Theater and Review Room Projection - Screen Luminance and Viewing Conditions
SMPTE RP 98-1995 Measurement of Screen Luminance in Theaters
SMPTE RP 51-1995 Screen Luminance and Viewing Conditions for 8-mm Review Rooms
SMPTE RP 59-1995 Color and Luminance of Review Room Screens for Viewing Motion-Picture Materials Intended for Slides or Film Strips

VESA — Video Electronics Standards Association

www.vesa.org. VESA has been working on several FPD interface standards that may be of interest.

FPDM — Flat Panel Display Measurements Standard

William Pavlicek, acting chair, Mayo Clinic,
Phone: 408-301-8098, E-mail: pavlicek.william@mayo.edu
Michael D. Grote, Vice Chair, NIDL (National Information Display Laboratory)
Phone: 609-734-2506, E-mail: mgrote@sarnoff.com

PUBLICATIONS OF INTEREST

Günter Wyszecki and W. S. Stiles, *Color Science: Concepts and Methods, Quantitative Data and Formulae*, 2nd Edition (1982, John Wiley & Sons). This is a classic reference work packed with information.
Peter A. Keller, *Electronic Display Measurement: Concepts, Techniques, and Instrumentation* (John Wiley & Sons in association with the Society for Information Display, 1997).
Flat-Panel Displays and CRTs (Van Nostrand Reinhold, New York, 1985) Lawrence T. Tannas, Jr., editor,
Yoshihiro Ohno, *Photometric Calibrations*, NIST Special Publication 250-37, U.S. Department of Commerce, National Institute of Standards and Technology, July 1997. This publication contains the details on how calibrations are made in photometry and describes the subtleties in the use of the instrumentation with a complete uncertainty analysis.
Barry N. Taylor and Chris E. Kuyatt, *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*, NIST Technical Note 1297, 1994 Edition.
Barry N. Taylor, *Guide for the Use of the International System of Units (SI)*, NIST Special Publication 811, 1995 Edition.

ABBREVIATIONS

Websites for Abbreviations:

Some web sites for finding acronyms:

http://www.onelook.com/
http://www.mtnds.com/af/
http://www.ict.etsi.fr/abrev.htm
http://www.techweb.com/encyclopedia/
http://www.ucc.ie/info/net/acronyms/acro.html
http://www.sematech.org/member/division/its/acronyms/acr_menu.htm
http://userpage.fu-berlin.de/~oheiabbd/veramain-e.cgi
http://www.sbri.com/a.htm

Abbreviations & Acronyms Associated with Display Industry:

ACATS ....Advisory Committee on Advanced Television Service (advisory committee created by the FCC in 1987)
AEA ....American Electronics Association
ALARA.......as low as reasonably achievable
AMLCD ......active matrix liquid crystal display
ANSI ....American National Standards Institute
ARPA ....Advanced Research Projects Agency (formerly DARPA)
ASTM ....American Society for Testing and Materials
ASS ....Swedish Nation Board of Occupational Safety and health
ATSC ....Advanced Television Systems Committee
ATTC ....Advanced Television Test Center (created by broadcasting companies and industry organizations in1988 to test proponent advanced television transmission systems. Alexandria, VA)
ATV ....advanced television
B-ISDN ....Broadband Integrated Services Digital Networks
BIPM...........Bureau International des Poids et Mesures (International Bureau of Weights and Measures)
BRDF ....bidirectional reflectance distribution function
BSDF...........bidirectional scattering distribution function
BTDF ....bidirectional transmittance distribution function
CATV..........cable TV
CCD ....charge coupled device
CCIR ....International Radio Consultative Committee (an organ of the International Telecommunication Union charged with studying technical and operating questions relating to radio services, including broadcasting, and issuing recommendations on the questions)
CCITT ....International Telephone and Telegraph Consultative Committee (an organ of the International Telecommunications Union charged with studying and issuing recommendations on technical, operating and tariff questions relating to telecommunications services other than radio communications services)
CCPR ....Consultatif Comité de Photométric et Radiométrie (Consultative Committee of Photometry and Radiometry)

CCT............correlated color temperature
CD..............committee draft
CEN............Comité Européen de Normalisation (European Standards Committee)
CENELEC...European Committee for Electrotechnical Standardization
CGPM.........Conférence Générale des Poids et Mesures (General Conference of Weights and Measures)
CIE.............Commission Internationale de l'Eclairage (International Commission on Illumination)
CIPM..........Comité International des Poids et Mesures (International Committee for Weights and Measures)
COHRS.......Committee on High Resolution Systems
CORM.........Council for Optical Radiation Measurements
CSF............contrast sensitivity function
CSL............Computer Standards Laboratory
DAB...........digital audio broadcasting
DARPA.......Defense Advanced Research Projects Agency
DIN............Deutsches Institut für Normung (German Institute for Standardization)
DIS.............draft international standard
DPI.............dots per inch
DSRC..........David Sarnoff Research Center
DUT...........display under test
EC..............European Community
EEC............European Economic Community (often use EC above as substitute)
EFTA..........European Free Trade Association
EIA.............Electronic Industries Association
EIAJ...........Electronic Industries Association of Japan
EL...............electroluminescent display
ESF.............edge spread function
FED............field emission display
FCC............Federal Communications Commission
FPD............flat panel display
FPDM.........Flat Panel Display Measurements Standard (VESA)
HDTV.........high definition television
HRI.............high resolution imaging
HRIS..........high resolution information systems
IEEE...........Institute of Electronics and Electrical Engineers
IEC.............International Electrotechnical Commission
ISO.............International Organization for Standardization
IS&T...........Society for Imaging Science and Technology
ITU.............International Telecommunication Union (a specialized United Nations agency)
JND............just noticeable difference
JT................joint technical committee
LCD............liquid-crystal display
LMD...........light measuring device (in VESA FPDM)
LSF.............line spread function

MAC ....Multiple Analog Component (the family of standards proposed by the EC for television transmission in EC member countries)
MPCD ....mean perceptible color difference
MPR ....Swedish National Board for Measurement and Testing
MTF ....modulation transfer function
MUSE ....Multiple Sub-Nyquist Sampling Encoding System (Japanese HDTV system)
NAB ....National Association of Broadcasters
NIDL...........National Information Display Laboratory (at DSRC)
NIST............National Institute of Standards and Technology (USA)
NPL ....National Physical Laboratory (UK)
NRC ....National Research Council (Canada)
NRLM.........National Research Laboratory of Metrology (Japan)
NTIA ....National Telecommunications and Information Administration
NTSC ....National Television System Committee
OSTP...........Office of Science and Technology Policy (part of the Executive Office of the President)
OTF ....optical transfer function
PIMA...........Photographic and Imaging Manufacturers Association
PD ....plasma display
PSF..............point spread function
PT................project team
PTB ....Physikalisch-Technische Bundesanstalt (Federal Physical Technical Institute [Germany])
SAE.............Society of Automotive Engineers
SI.................Systéme International d'Unités (International System of Units)
SID ....Society for Information Display
SMPTE........Society of Motion Picture and Television Engineers
SPIE ....International Society for Optical Engineering (Society of Photo-Optical Instrumentation Engineers)
SSI...............Swedish National Institute of Radiation Protection
STN ....super twisted nematic (liquid crystal)
TAG ....technical advisory group
TC ....technical committee
TEPAC........Tube Engineering Panel Advisory Council (for EIA)
TEB ....TEPAC Engineering Bulletin
TEP ....Tube Engineering Panel
TFT ....thin film transistor
TN ....twisted nematic (liquid crystal)
USDC..........United Sates Display Consortium
USNC..........US National Committee of the IEC
VESA ....Video Electronics Standards Association (vee'-suh)
VDT ....video display terminal
VDU............video display unit
WG..............working group

OTHER WEBSITES OF INTEREST

http://www.osa.org/	Optical Society of America
http://www.spie.org/	International Society for Optical Engineering
http://optics.org/	Photonics Resource Center (SPIE)
http://www.imaging.org/	Society for Imaging Science and Technology (IS&T)
http://www.sid.org/	Society for Information Display
http://www.ieee.org/	Institute of Electrical and Electronic Engineers
http://www.nist.gov/	National Institute of Standards and Technology

http://physics.nist.gov/Divisions/Div844/div844.html
Optical Technology Division, NIST
http://www.boulder.nist.gov:/div815/
Optoelectronics Division, NIST
http://www.eeel.nist.gov/811/eitg/eit_docs/fpdlab.html
FPD Lab (FPDL), NIST
ftp://ftp.fpdl.nist.gov/pub/ Publications of the FPDL, NIST
This document: ftp://ftp.fpdl.nist.gov/pub/seminars/ApSem01.pdf

The following pages contain the presentation slides.

Slide 1

Flat Panel Display Measurements and Standards

SID2001 Applications Seminar

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NIST FLAT PANEL DISPLAY LABORATORY
Edward F. Kelley, 301-975-3842, kelley@nist.gov

Slide 2

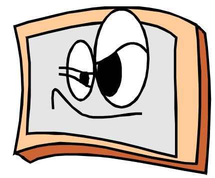
Need for Good Display Metrology

- Good Display Metrology—What Is It?
  - ***Robust*** — *insensitive to measurement apparatus*
  - ***Unambiguous*** — *clear method and result goal*
  - ***Meaningful*** — *measuring what the eye appreciates*
  - ***Reproducible*** — *everybody can get the same results*
  - ***Extensible*** — *applicable to many different technologies*
- Level Playing Field — Competition
  - ***Between FPDs within a technology***
  - ***Between different technologies of FPDs***
- Specification Language Defined
  - ***Task dependent specifications possible***
  - ***Enables clarity and removes ambiguity***
- Measuring What the Eye Sees
  - ***Ergonomics and vision science must be based upon good metrology***

NIST 2

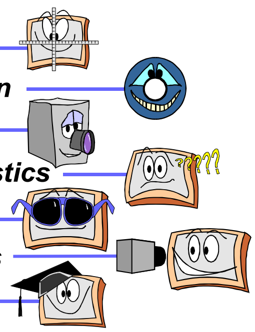
Slide 3

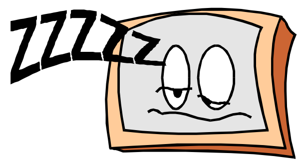
FPD Measurements and Standards



Display Metrology

- *Task Dependent Setup*
- *Redundancy & Calibration*
- *Devices & Deployment*
- *Measurements & Diagnostics*
- *Reflection Metrology*
- *Projection Measurements*
- *Tips & Things*





Display Standards

- *Partial Listing & Contact Information*
- *VESA FPDM*

Where possible the information contained in this seminar is linked to the FPDM via section number placed in brackets, e.g., [FPDM A102] .

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Slide 4

FPD Measurements and Standards, Cont.

SI UNITS USED THROUGHOUT PRESENTATION

SI = Systéme International d'Unités
(International System of Units)

Equations can be different using Imperial units. Be careful!

SI: L in cd/m², E in lx

$$L = \frac{\beta}{\pi} E$$

Imperial: L in fL, E in fc

$$L = \beta E$$

SI (Metric) and Imperial Photometric Conversion Table

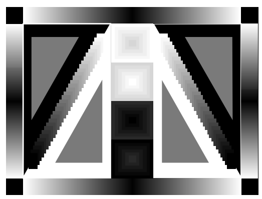
↓ = #### * →	**cd/m²** = lm/sr/m²	**fL** = lm/sr/ft²	**lx** = lm/m²	**fc** = lm/ft²
1 cd/m² = 1 lm/sr/m²	1	0.2919		
1 fL = 1 lm/sr/ft²	3.4263	1		
1 lx = 1 lm/m²			1	0.09290
1 fc = 1 lm/ft²			10.76	1
origin of number:	$m^2/\pi/ft^2$ = 3.426259…	$\pi ft^2/m^2$ = 0.2918635…	m^2/ft^2 = 10.76391…	ft^2/m^2 = 0.09290304…
1 = →	$3.4263 \frac{cd/m^2}{fL}$	$0.2919 \frac{fL}{cd/m^2}$	$10.76 \frac{lx}{fc}$	$0.09290 \frac{fc}{lx}$

NIST 4

Slide 5

Task-Dependent Setup

- **Proper Setup Depends Upon Display Task.**
  - ***How will the display be used?***
  - ***What environment (ambient, surround)?***
  - ***Are there manufacturing setup specifications?***
  - ***Gray scales near black and near white are often useful, but may not be sufficient. [FPDM 301-3A]***
  - ***Might also try a face as well as a scene.***



NIST

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Slide 6

Task-Dependent Setup, Cont.

- **Setup Conditions Should Remain Fixed.**

  During series of measurements the task-specific setup conditions should not be changed to improve any single measurement, unless the task calls for such changes. [FPDM 301-2E, 305-3]

- **Warm-Up Time May Be Needed.**

  During the warm-up of the display is a good time to examine the display for defects and problems. Try out many different patterns and images suitable to the intended display task. [FPDM 301-2D]

NIST

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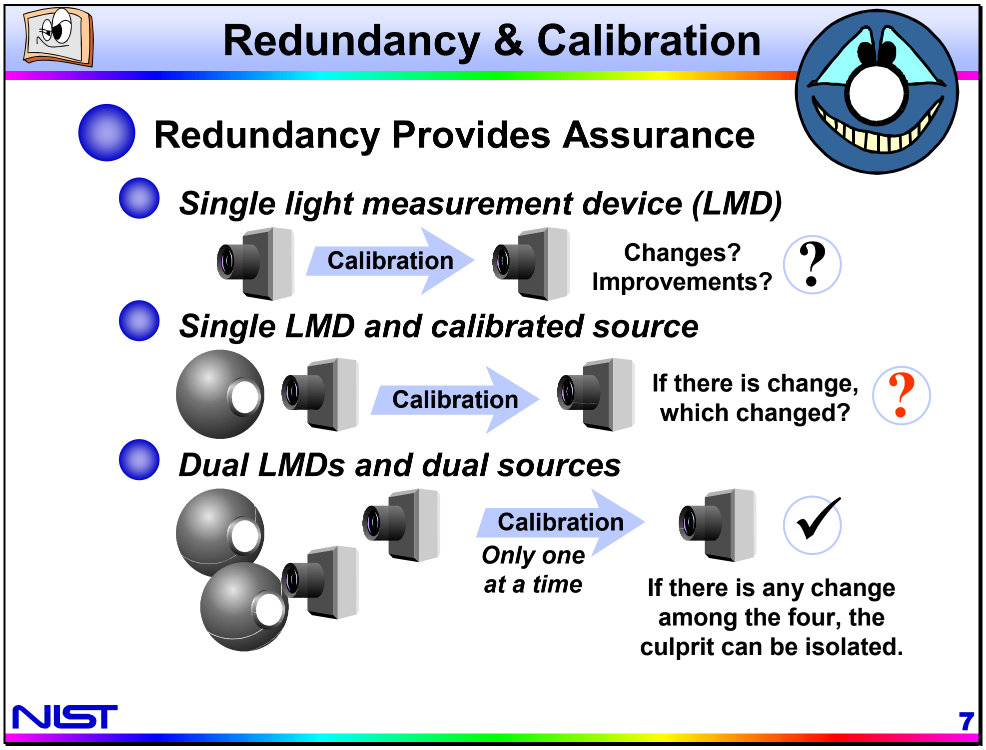
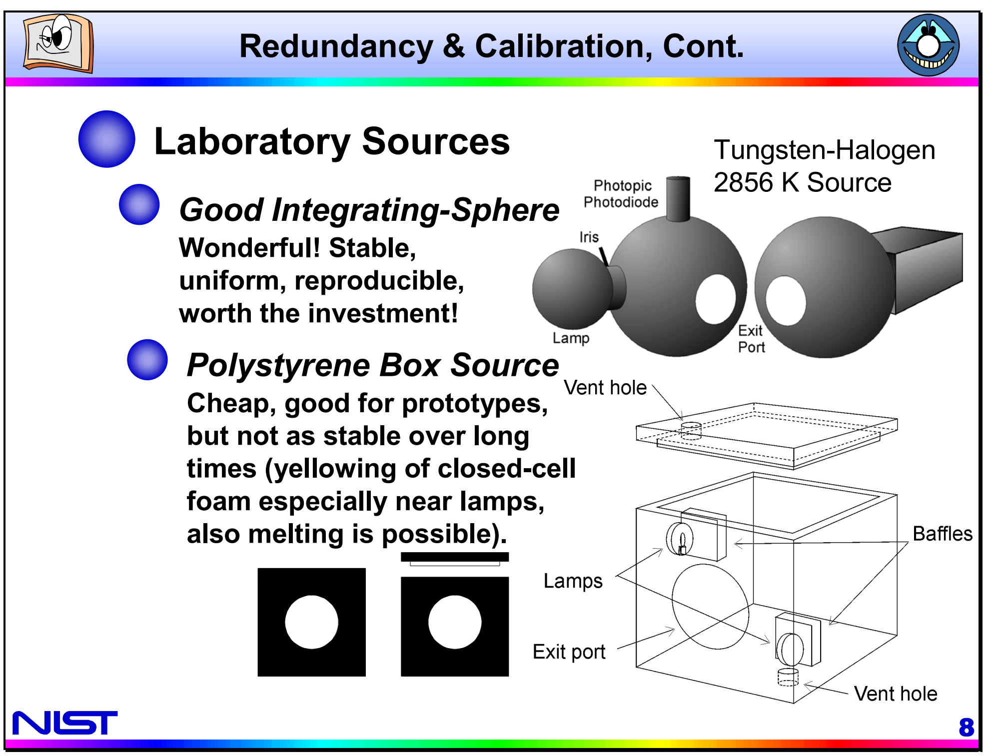
Slide 7



Slide 8

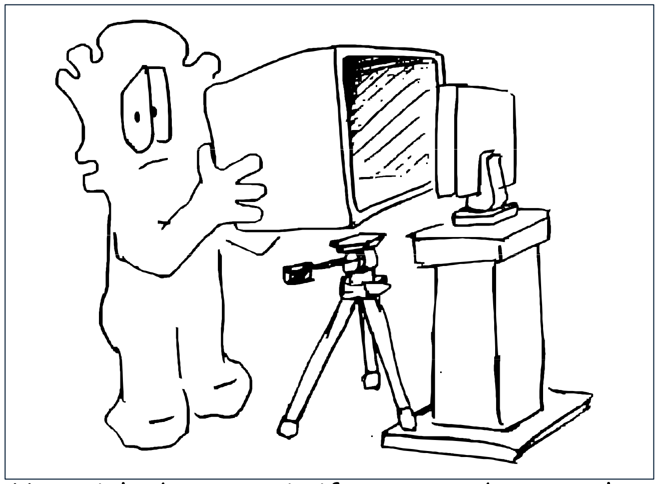


Slide 9

Redundancy & Calibration, Cont.

RUSTIC METROLOGY

However, if you are found using white-closed-cell polystyrene box sources, your reputation may suffer.



You might be a rustic if you use a beer cooler as an integrating sphere (or light source).

NIST

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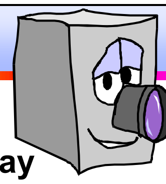
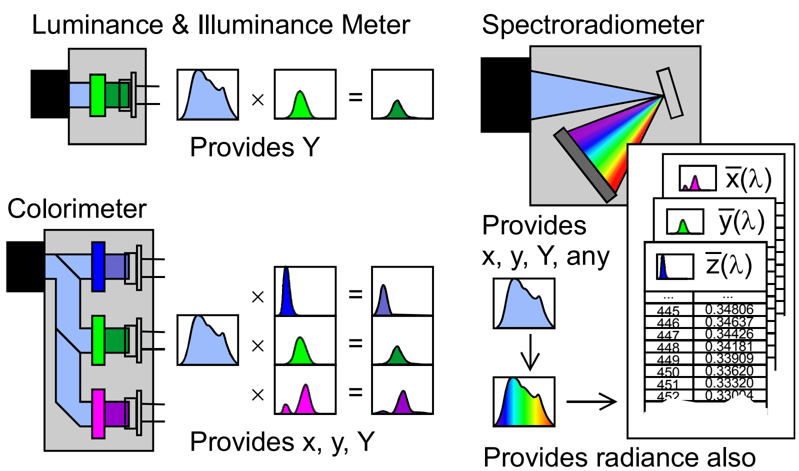
Devices & Deployment



- **DEVICES: Colorimeter, spectroradiometer, luminance meter, illuminance meter, 2D array devices…[FPDM A103]**



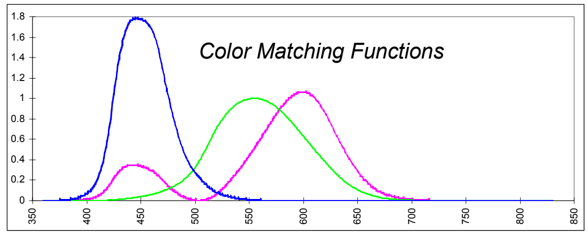
NIST

Slide 11

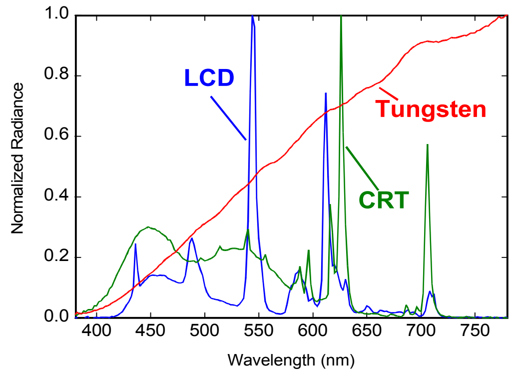
Devices & Deployment, Cont.

Filtered Devices

Luminance meters, illuminance meters, colorimeters, photopic CCD cameras...



Small errors (especially in the wings) in the filters that duplicate the color matching functions can affect narrow-band source measurements more than broad-band source measurements.

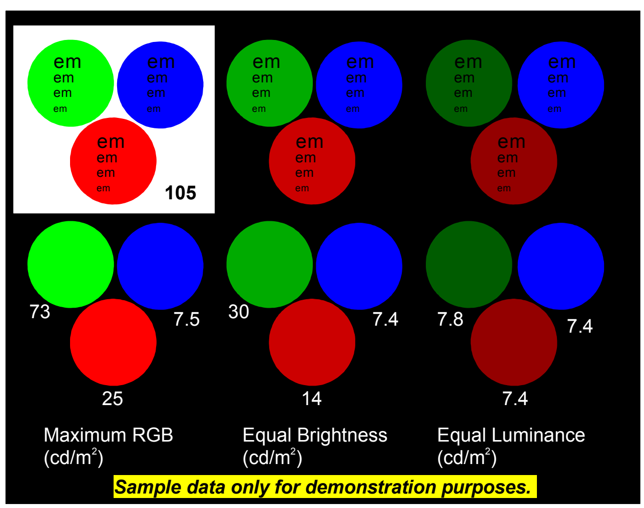


Slide 12

Devices & Deployment, Cont.

What Luminance Is and Is Not...

The luminance metric attempts to match the spatio-temporal response of the eye. Two colors of equal luminance may not be perceived as having the same brightness, especially since brightness can depend upon ambient conditions.



The center triads (when originally created on a CRT monitor) appeared to have the same brightness. The right triads were adjusted to have the same luminance as the blue dot (all blue dots should be the same).

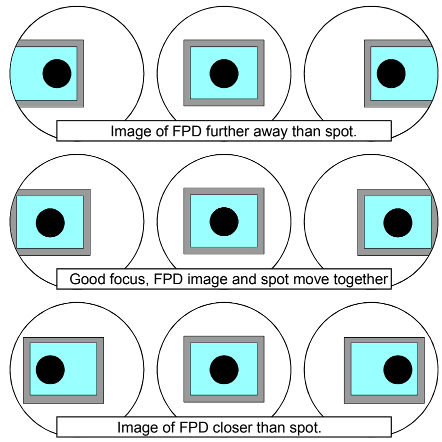
Slide 13

Devices & Deployment, Cont.

Viewport Device Focusing

- ***Focus on object being measured.*** ***[FPDM A103-3A]***
- ***Integrating sphere sources: Focus on exit port.***
- ***Use parallax method to be sure proper focus is obtained.***

<u>Use parallax method</u> if uncertain: Focus eyepiece on spot. Then move your eye slightly back and forth (or up and down by slightly rotating your head) and see if the image and the measurement spot stay together. Change the focus of the main instrument lens until they appear to move together.



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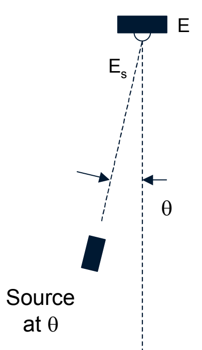
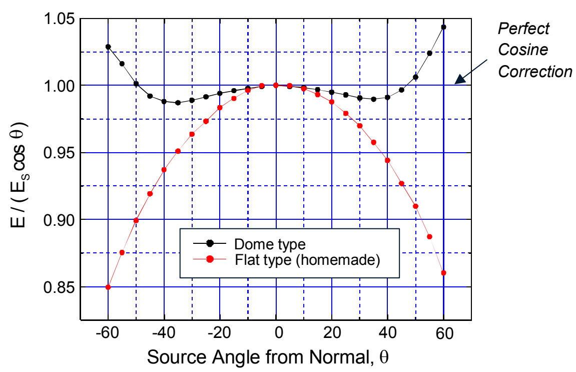
Devices & Deployment, Cont.

Illuminance Meter — Cosine Corrected?

For small source at θ, illuminance goes as cosθ.

If illuminance meter is cosine corrected, E/cosθ should be constant. Should know if it is not.





Example ONLY! Don't lift these data and use elsewhere.

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Devices & Deployment, Cont.

- **Colorimetry vs. Electronics:**

  We are NOT measuring voltages. Colorimetry (and photometry) is not as precise—it is more like trying to measure an electric field than a voltage.

- **~~Accuracy vs. Precision~~**

  These terms are not precisely defined [snicker]. Must learn to use proper terminology…[FPDM A221]

  ISO (International Organization for Standardization) Guide to the Expression of Uncertainty in Measurement, 1995.

  Can also see: ANSI/NCSL Z540-2-1997 "U.S. Guide to the Expression of Uncertainty in Measurement," (American National Standards Institute/National Conference of Standards Laboratories), first edition, October 9, 1997; or Barry N. Taylor and Chris E. Kuyatt, Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, NIST Technical Note 1297, 1994 Edition.

  Thus: Old "two-sigma" uncertainty now becomes "<u>expanded uncertainty with a coverage factor of two</u>" (or "k = 2"). A "one-sigma" uncertainty is the "<u>combined standard uncertainty</u>" and is the root-sum-of-squares of the component uncertainties. "<u>Repeatability</u>" means shot-to-shot precision. "<u>Reproducibility</u>" means configuration-to-configuration precision.

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Slide 16

Devices & Deployment, Cont.

- **Measurement Uncertainty & Repeatability**
  - **Photometry:**
    - ***No reliable standard sources exist to enable 0.1 % or less relative calibration uncertainty (when using "uncertainty" the ± is assumed)***

      National Lab (e.g. NIST) can do about 0.8 % (k=2) uncertainty.

      Secondary calibration might be 2 % (k=2).

      Delivered instrument guarantees 4 % or so (k=2) for long term.

    - ***Thus, a 4 % relative measurement uncertainty might be expected when comparing luminance (illuminance) results with others around the world.***

    - ***The luminance (illuminance) repeatability can be smaller than 1/10 the measurement relative uncertainty (≤ 0.5 % often 0.1 %).***

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Devices & Deployment, Cont.

Measurement Uncertainty & Repeatability, Cont.

- **Colorimetry:**
  - ***Chromaticity coordinates are based on ratios of tristimulus values. If detector is linear and has the proper spectral response, the chromaticity-coordinate measurements can be less uncertain than the luminance measurement***
  - ***A ±0.005 measurement uncertainty might be expected when comparing chromaticity coordinate results (tungsten-halogen source may do better).***
  - ***The chromaticity coordinate repeatability will probably be about ±0.002 or (much) less.***

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Devices & Deployment, Cont.

Measurement Uncertainty & Repeatability, Cont.

- **Display Measurement Assessment Transfer Standard — DMATS (dee´-mats)**

  Collaboration with the Optical Technology Division of NIST's Physics Lab (Drs. Yoshi Ohno and Steve Brown)

  - ***WHAT IT IS: A uniformly backlit target assembly that exploits the capability of the measuring instrumentation in participating laboratories.***
  - ***HOW IT WORKS: NIST measures, participating lab measures what it wants to, NIST re-measures, results shared with lab (NOT a calibration!).***
  - ***RESULTS: Anonymous comparison shows what industry can expect in making straightforward measurements of displays.***

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Slide 19

Devices & Deployment, Cont.

How Many Measurements Are Needed?

- ***Try it and see!***
  Take seven measurements of a white screen, calculate the mean and standard deviation. If the standard deviation is about the same size as the repeatability, one measurement should be adequate. As long as the uncertainty of measurement is much greater than the repeatability, we can feel comfortable with making single measurements. [FPDM 301-2K]
- ***Repeat whenever there is a question.***
  If you wonder about any other color or level, repeat the above with the new color.
- ***Watch for short integration times.***
  When a short measurement time interval is used with a pulsed (scanned) light source (some displays) you don't always capture the same number of frames unless the detector is synchronized with the display. (See next slide for an example.)

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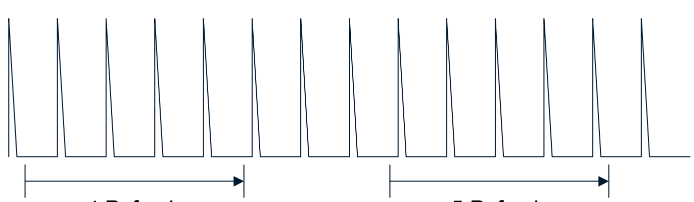
Slide 20

Devices & Deployment, Cont.

Short Integration Times — Possible Errors from Refresh of Screen

If screen refreshes (as with a CRT) and it is bright so that the detector uses a short integration time, can get measurement errors from the light of ±1 frame. Average many measurements or use good (and calibrated) neutral density filter to reduce luminance.



4 Refreshes *5 Refreshes*

Same measurement window in both cases, but depending upon when the measurement is made, a relative deviation of up to 20% (or 25%) can be seen in this case.

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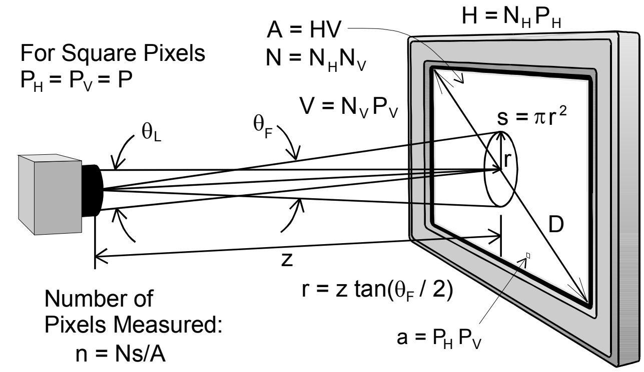
Slide 21

Devices & Deployment, Cont.

Subtense of Detector & Region Measured

Be aware of rays of light contributing to the signal. Some displays have a viewing-angle sensitivity, and we can inadvertently measure what our eyes don't see. [FPDM A102-1]



Usually, the angular field of view quoted for a luminance meter refers to the angle θ_F measured at infinity focus. For nearer subjects the angle θ_F may be slightly different.

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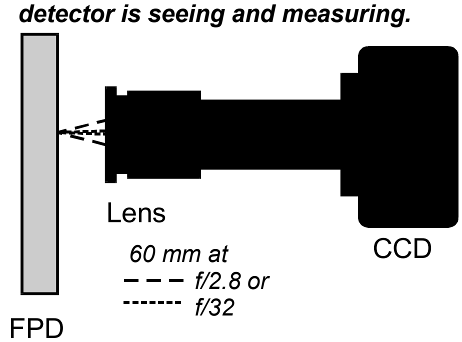
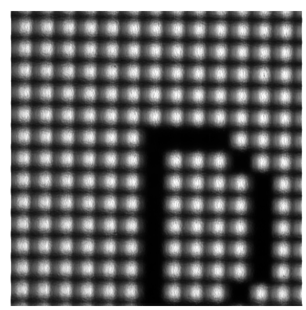
Slide 22

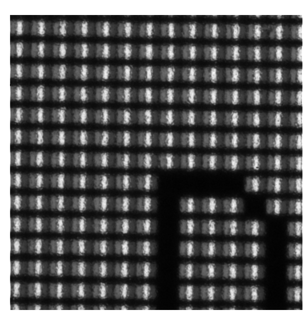
Devices & Deployment, Cont.

Subtense of Lens a Factor

Top photo at f/2.8 gathers light from many directions. Bottom photo at f/32 is more the way the eye sees things. (Lens f# = f/D=focal-length/diameter: At f/2.8 f=60 mm lens has D=21 mm whereas at f/32 D=1.9 mm.) Diagram is approximately to scale. We must be concerned about just what the detector is seeing and measuring.







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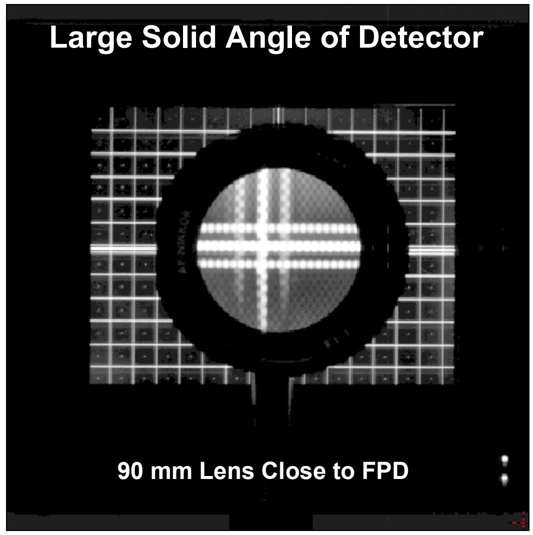
Slide 23

Devices & Deployment, Cont.

Subtense of Lens a Factor , Cont.

Note how much lighter the black pixels are at the top compared to the bottom or central regions.



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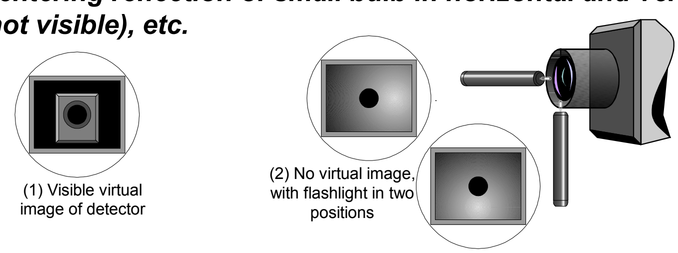
Devices & Deployment, Cont.

Determination of Screen Normal

- ***±1° is sloppy — 1° = the angular width of your thumbnail or little finger with an out-stretched arm, twice the angular width of the sun or moon. Try for ±0.3° or ±0.1° (or even better!).***
- ***Methods to find normal [FPDM A115] :***

  1. aligning virtual image of detector lens (if visible) with center of eyepiece, or

  2. centering reflection of small bulb in horizontal and vertical (if not visible), etc.



- ***Note: Not all screens should be measured at normal. It depends upon design and task.***

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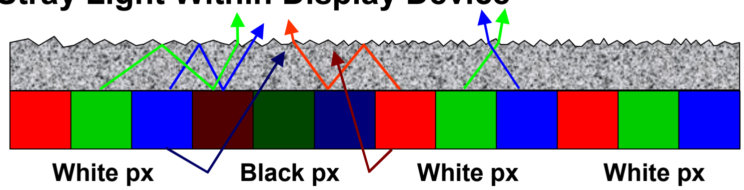
Slide 25

Devices & Deployment, Cont.

Stray Light Management

Stray Light Within Display Device



- **FPDs — front surface near pixels permits strong diffusing surface with some resulting internal scattering and reflections.**
- **CRTs — front surface significantly separated from pixels provides more reflection plus internal scattering and beam halation behind pixel surface.**

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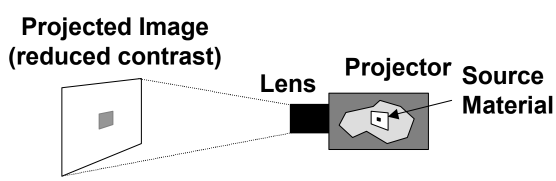
Slide 26

Devices & Deployment, Cont.

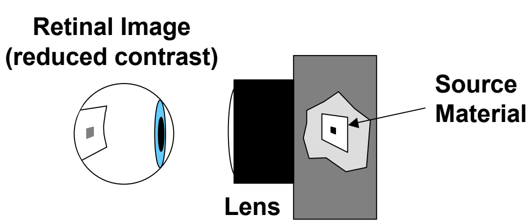
Stray Light Management, Cont.

Stray Light Within Display Device, Cont.

- **Projection Displays: Projection lens veiling glare**



- **HMDs: Relay lens veiling glare**



STRAY LIGHT IS INTRINSIC TO SOME DISPLAYS
We can't do anything about it.

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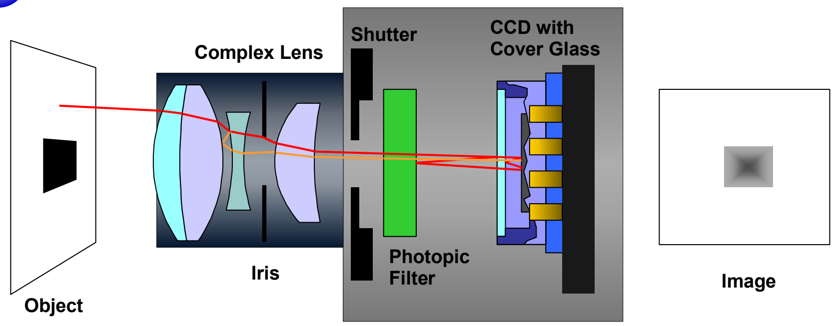
Devices & Deployment, Cont.

Stray Light Management, Cont.

Stray Light Within Detector – Veiling Glare



Reflection off of internal lens structure

Reflection between lens surfaces

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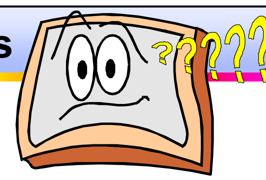
Slide 28

Measurements and Diagnostics



Diagnostics— A Wise Choice

- ***Diagnostics Often Ignored***
  - Too time consuming — they slow us down!
  - Ostrich effect — we don't want to know if we have problems.
  - We can't afford the extra equipment to do them.

- ***Benefits of Diagnostics***
  - Problems revealed early, before much data are recorded
  - Confidence in apparatus, personnel, and procedures
  - Heightens awareness of how simple things can go wrong

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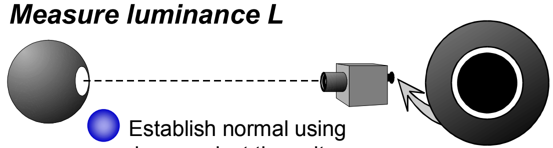
Slide 29

Measurements and Diagnostics, Cont.

Luminance & Illuminance Meter Comparison

Does your illuminance meter agree with your luminance meter?

- ***Measure luminance L***

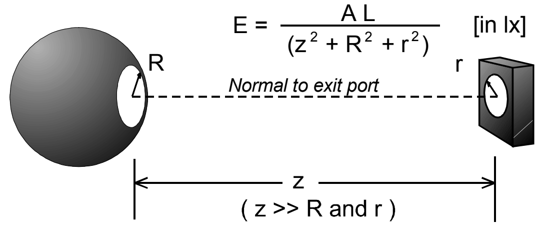


- Establish normal using a mirror against the exit port.
- Move luminance meter back far enough that the measurement aperture almost fills the exit port.

- ***Measure illuminance and compare with calculated E.***
  - Reflections from surrounding objects must be carefully eliminated. Matte-black baffles made from thin material may be helpful, or gloss-black frustums.
- Accurate measurement of exit port area is VERY important.

Exit port area $A = \pi R^2$ assuming it is round.

$$E = \frac{A\,L}{(z^2 + R^2 + r^2)} \quad \text{[in lx]}$$



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Slide 30

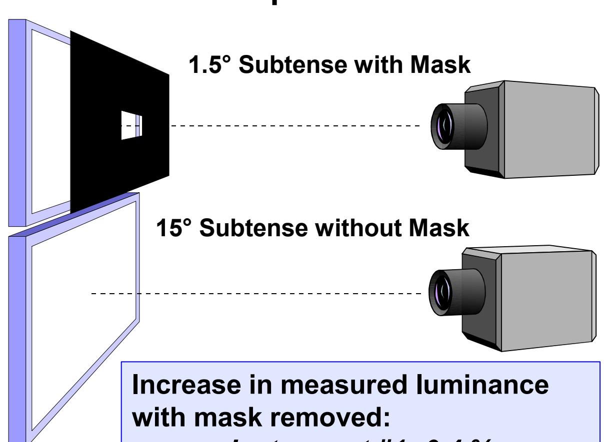
Measurements and Diagnostics, Cont.

Avoiding Veiling Glare

Veiling Glare Can Affect Simple Measurements

Measurement of Full-Screen White

Comparison of two identical luminances having different angular sizes. Same screen with & without mask (1.5° or 15° angular diameter of white area from lens of detector)



Increase in measured luminance with mask removed:

Instrument #1	***0.4 %***
Instrument #2	***1.3 %***
Instrument #3	***4.8 %***

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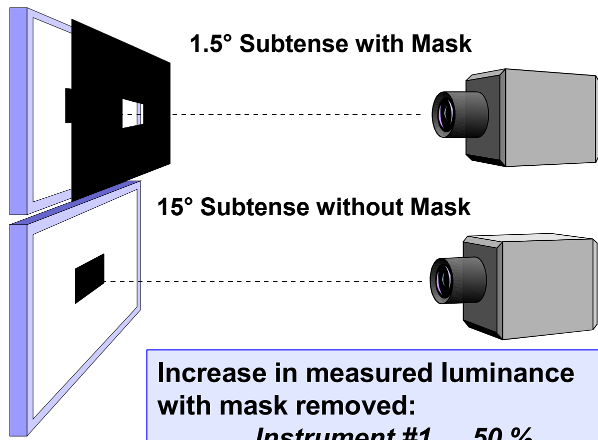
Measurements and Diagnostics, Cont.

Avoiding Veiling Glare, Cont.

Veiling Glare Can Affect Simple Measurements, Cont.

Measurement of Black Rectangle on White

This shows how important it is to anticipate veiling glare in the detection system. Same screen with & without mask (1.5° mask hole, 15° angular diameter of white area from lens of detector)



Increase in measured luminance with mask removed:

Instrument #1	***50 %***
Instrument #2	***325 %***
Instrument #3	***1200 %***

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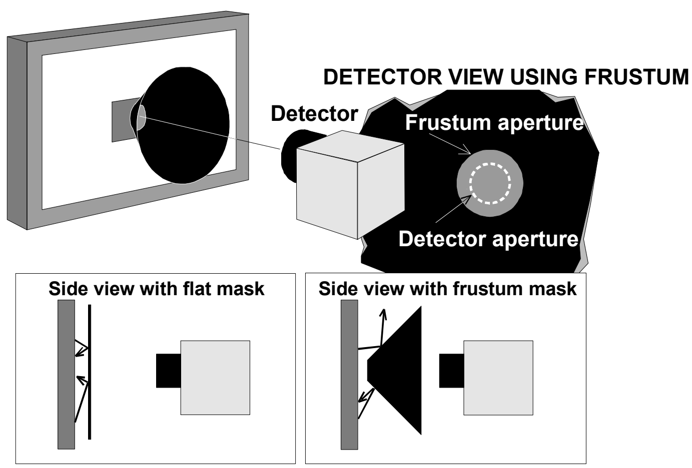
Slide 32

Measurements and Diagnostics, Cont.

Avoiding Veiling Glare, Cont.

Use of Masks — Flat and Frustum



With some very high contrast displays, the back reflections off flat masks can cause substantial errors.

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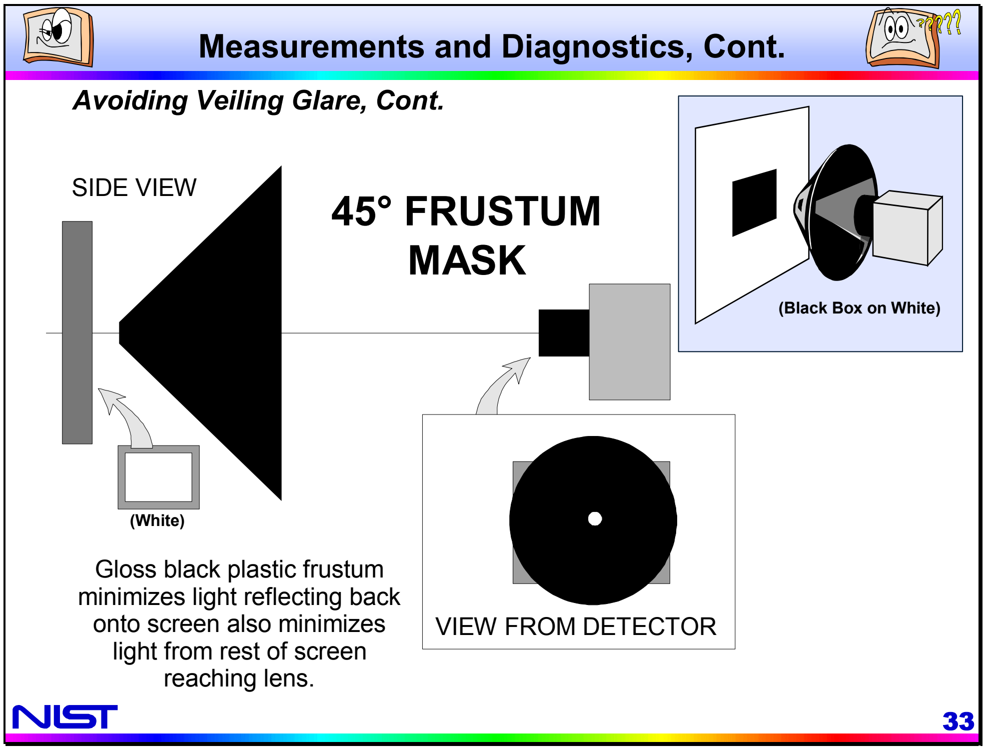

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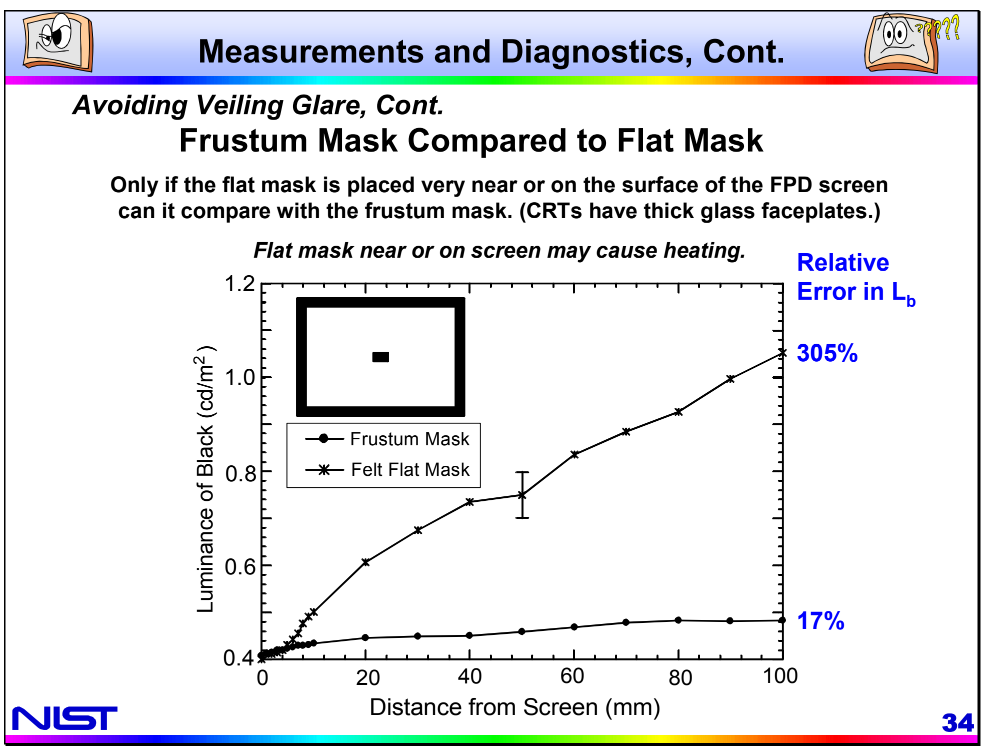


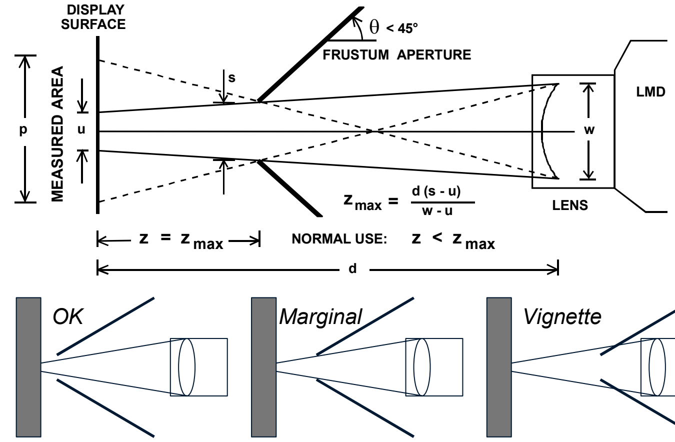
Slide 35

Measurements and Diagnostics, Cont.

Avoiding Veiling Glare, Cont.

Avoid Vignette (vin-yet´) from Mask

Keep in mind that if the mask is too close to the lens it can interfere with the measurement (especially when the hole is smaller than the lens).



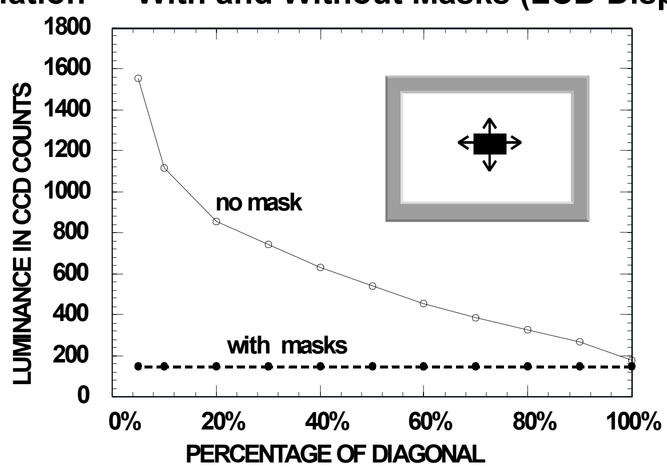
NIST

Slide 36

Measurements and Diagnostics, Cont.

Avoiding Veiling Glare, Cont.

Halation — With and Without Masks (LCD Display)

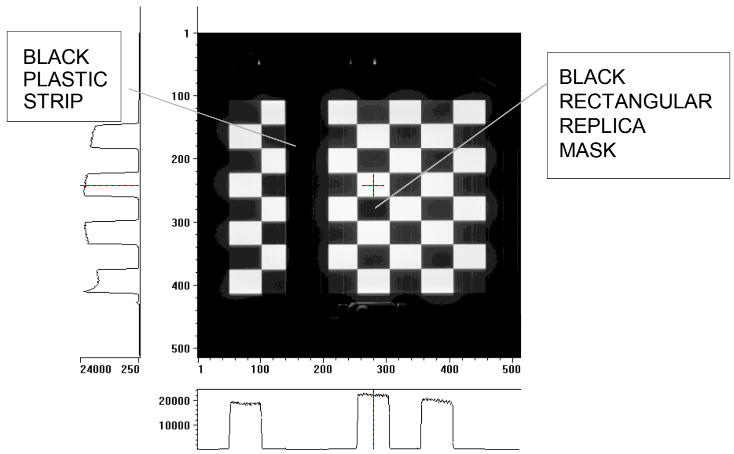


NIST

Slide 37

Measurements and Diagnostics, Cont.

- **Small Area Measurements**
  - **Replica Masks**



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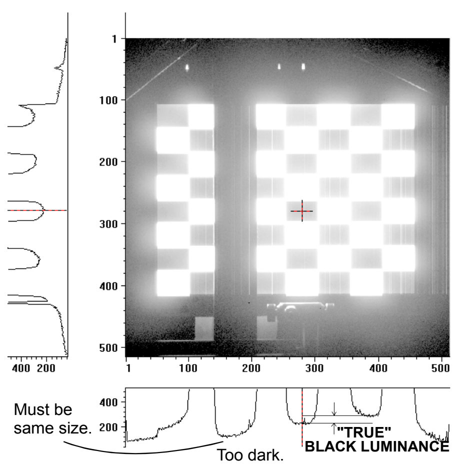
Slide 38

Measurements and Diagnostics, Cont.

Small Area Measurements, Cont.

- **Replicas, Same Size As Black Region**
  - *Replica masks must be close to (±10 %) the size of the black area to be measured.*
  - *It is often a good idea to check your measurements using a NDF (neutral density filter) replica mask (at same T).*



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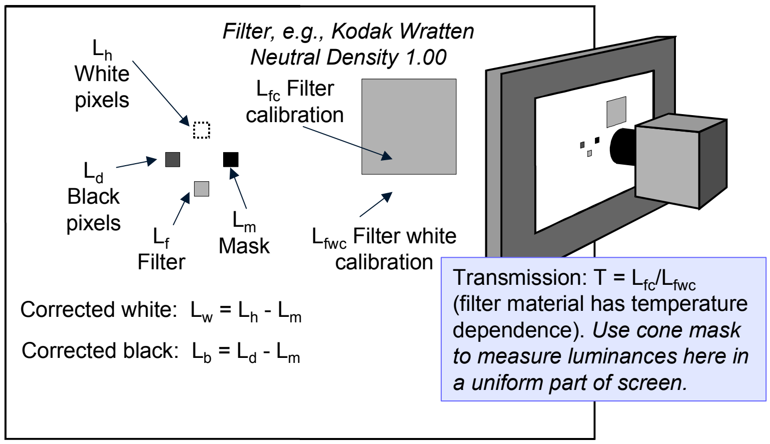
Slide 39

Measurements and Diagnostics, Cont.

Small Area Measurements, Cont.

Replica Mask with Diagnostic Filter Mask



Check: Does $(L_f - L_m)/L_w = T$???

If so, measurement is probably good. (At least a lot better than if we didn't do anything!)

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Slide 40

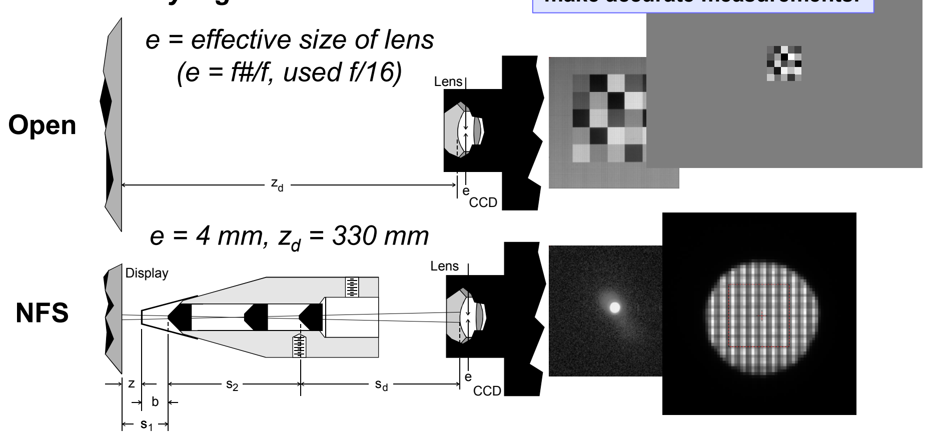
Measurements and Diagnostics, Cont.

Small Area Measurements, Cont.

Narrow Frustum SLET (NFS)

SLET = Stray Light Elimination Tube

Dark regions can be seriously corrupted by glare (n X 100 %). Correction for glare or the elimination of it is required to make accurate measurements.



Credit: A. Badano and M. J. Flynn, "Method for measuring veiling glare in high performance display devices," Applied Optics, Vol. 39, No. 13, pp. 2059-2066, May 2000.

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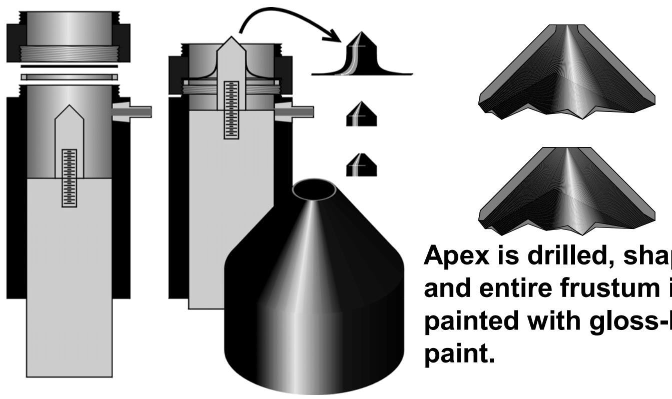
Slide 41

Measurements and Diagnostics, Cont.

Small Area Measurements, Cont.

- **Small Frustums: Vacuum Formation of Gloss-Black Vinyl**



Apex is drilled, shaped, and entire frustum is painted with gloss-black paint.

Material: 0.25 mm thick originally, heated until flexible, resulting formed thickness from 0.12 mm to 0.05 mm thick.

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Slide 42

Measurements and Diagnostics, Cont.

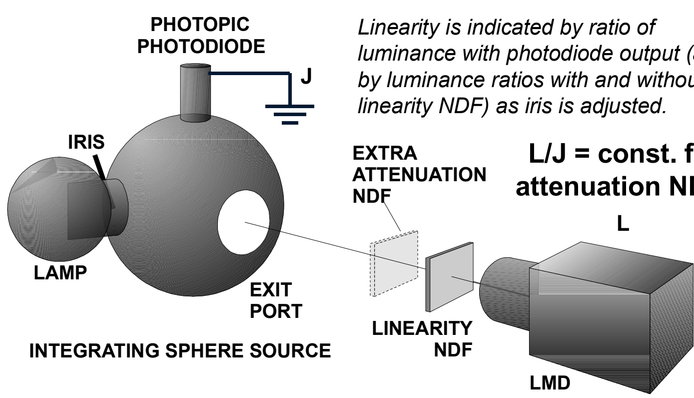
- **Linearity Diagnostics Using NDFs**

Neutral Density Filters to Test Linearity

The color of the light should not change or light-measuring device (LMD) will report non-linearities. Use thin-film metallic NDFs and an aperture-controlled lamp.

Linearity is indicated by ratio of luminance with photodiode output (also by luminance ratios with and without the linearity NDF) as iris is adjusted.

L/J = const. for each attenuation NDF used.



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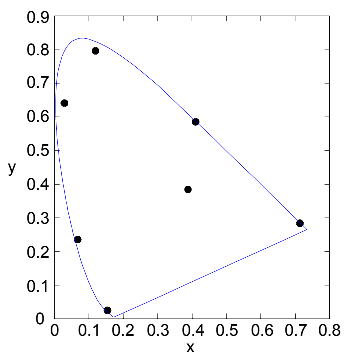
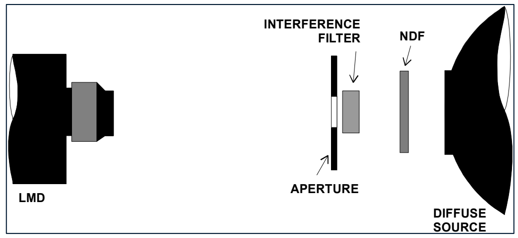
Measurements and Diagnostics, Cont.

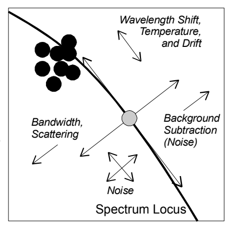
Color Diagnostics Using IFs

Interference Filters Test Color Measurement

Assuming white point calibration is accurate, the nearness of the (x,y) of narrow-band interference filters to the spectrum locus provides an indication of instrument's accuracy within the spectrum locus.







Ideal distance from spectrum locus is determined by bandwidth of filter and curvature of locus.

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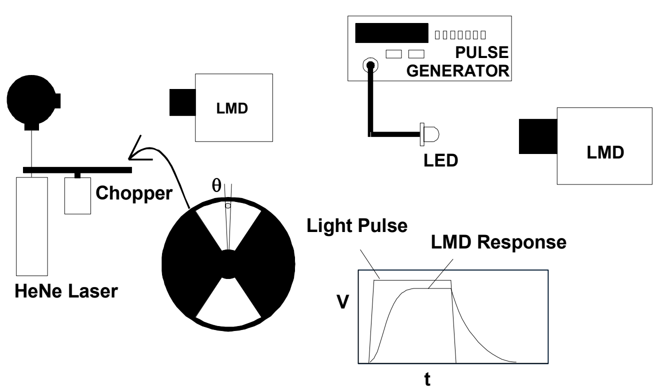
Measurements and Diagnostics, Cont.

Temporal Diagnostics

Response-Time Measurement

Use chopper and laser into inexpensive integrating sphere for submillisecond region. Use fast LED and pulse generator for ten nanosecond region or longer.



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Slide 45

Measurements and Diagnostics, Cont.

Array Detector Problems

- **Photopic Response**

  Sensitivity to IR can seriously corrupt what was intended to be a luminance measurement.

- **Flat-Field Correction**

  Nonuniformity partially corrected by FFC. FFC may change with lens and object configurations.

  We are assuming a background subtraction is performed before the FFC. The FFC can change for the type of lens used, the f-stop, the focus, the size of the light-area measured and its distance, etc. Very difficult to accurately create because a truly uniform source of sufficient size is hard to obtain and because the correction needed can change so much with conditions. Be careful. What will serve as a FFC for one configuration may not for another!!

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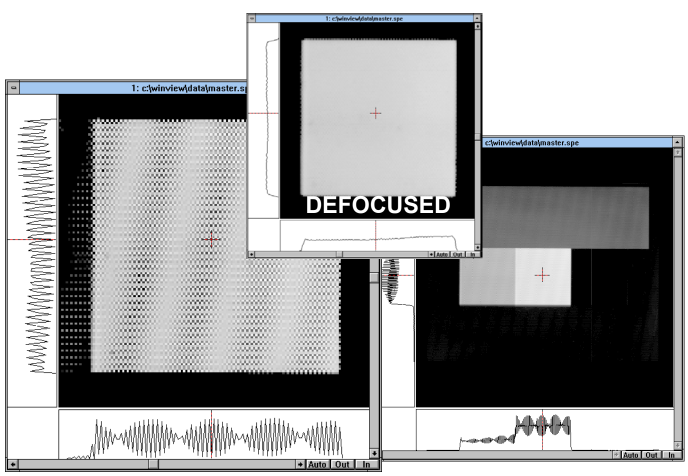
Measurements and Diagnostics, Cont.

Array Detector Problems, Cont.

Spatial Aliasing (Moiré Patterns)



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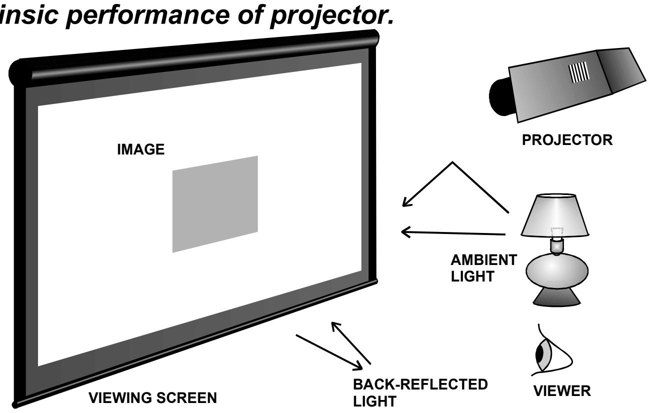
Projection Display Measurements

Accounting for Stray Light

Projector should not be blamed for the less than perfect viewing conditions of the screen and room. GOAL: Obtain intrinsic performance of projector.



Even in a black-walled darkroom using a black screen with a checkerboard displayed, significant errors of several tens of percent can be made if we are not careful.

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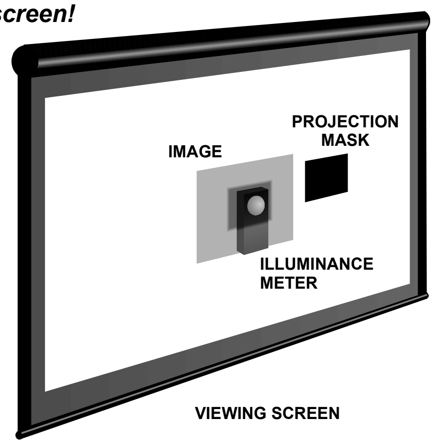
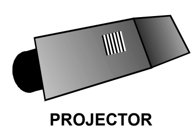
Projection Display Measurements, Cont.

Accounting for Stray Light in Room – Projection Mask

Use a projection mask (wider than the lens diameter) placed from 35 cm to 60 cm from the screen. Objects in room and room walls reflect light from the white screen back into black area. This can be a serious corruption of the black even in a darkroom and even using a black screen!





Illuminance measured behind the mask must be subtracted from the measurement without the mask to obtain an accurate measurement of black or white.

Compares well with SLET (± 1 %) in a darkroom and can possibly be used in a darkened room.

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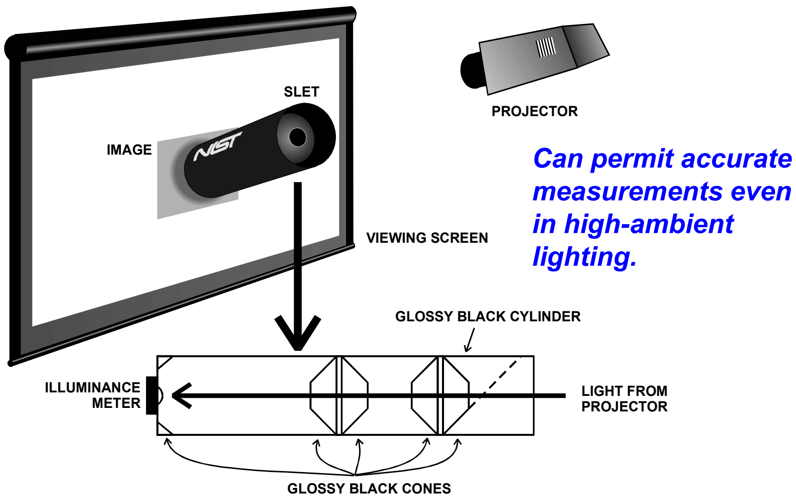
Projection Display Measurements, Cont.

Stray-Light Elimination Tube (SLET)

Can permit accurate measurements even in high-ambient lighting.



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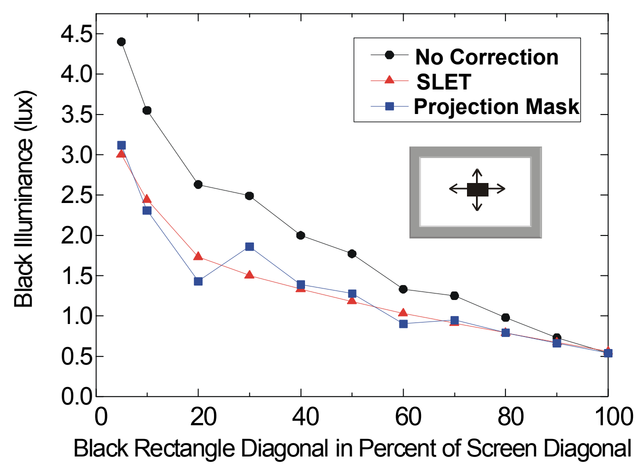
Projection Display Measurements, Cont.

Correction for Stray Light Necessary Even in Darkroom.



~30% Black Corruption from Reflected Light in a Black-Walled Darkroom

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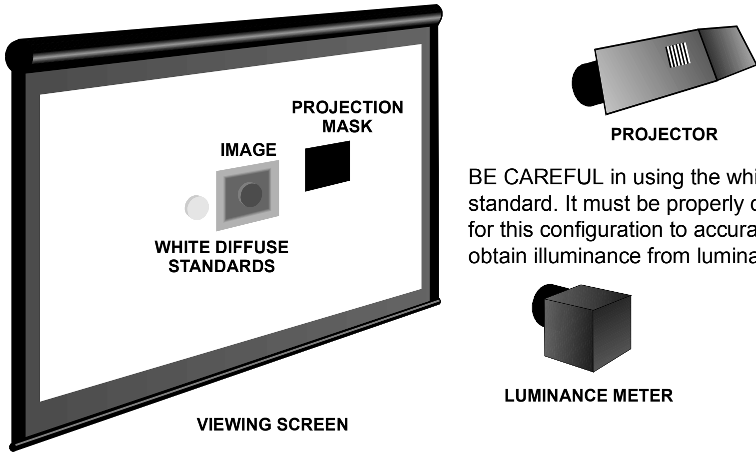
Projection Display Measurements, Cont.

Making Luminance Measurements

Screen gain is very directional. Can avoid screen effects by using calibrated diffuse white standard and converting to illuminance.



BE CAREFUL in using the white standard. It must be properly calibrated for this configuration to accurately obtain illuminance from luminance.

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Canonical Reflection Terminology

Reflectance Factor, R:

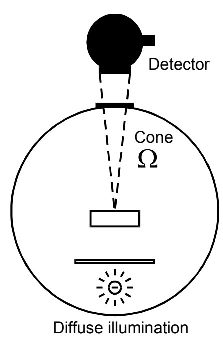
Ratio of the reflected flux from the material within a specified cone to the flux that would be reflected from a perfect (reflecting) diffuser (perfectly white Lambertian surface) under the same specified illumination:

$$R = \left(\frac{\Phi_{\text{material}}}{\Phi_{\text{perfect diffuser}}}\right)_{\text{Cone}}\Bigg|_{\text{For Specified Illumination Conditions}}$$

Special cases:

Luminance Factor β: $\Omega \to 0, \quad R \to \beta$

Reflectance ρ: $\Omega \to 2\pi, \quad R \to \rho$



Cone shown: Ω = 0.0379 sr for 12.6° apex (6.3° inclination angle from normal)

Example only, many other configurations possible.

Reference: CIE Publication #46 & #44

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Canonical Reflection Terminology, Cont.

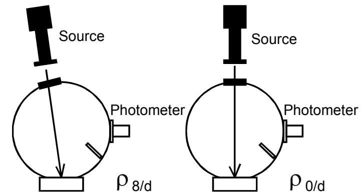
Reflectance, Diffuse Reflectance ρ :

Ratio of the (entire, $\Omega = 2\pi$) reflected flux to the incident flux:

$$\rho = \frac{\Phi_r}{\Phi_i}$$

Note notation: source/detector

Specify angle or use "d" for diffuse.

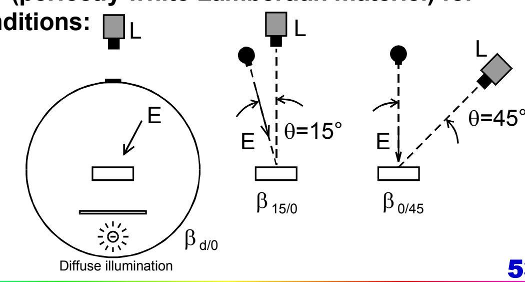


Luminance Factor β :

Ratio of the luminance of the object to that of the luminance of a perfect reflecting diffuser (perfectly white Lambertian materiel) for identical illumination conditions:

$$\beta = \frac{L}{E/\pi}$$

Note: luminance coefficient: $q = \beta / \pi$



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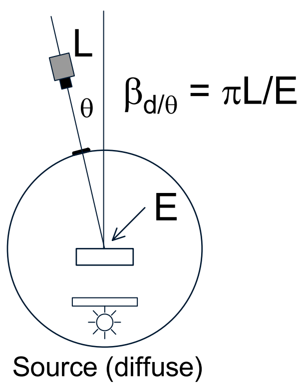
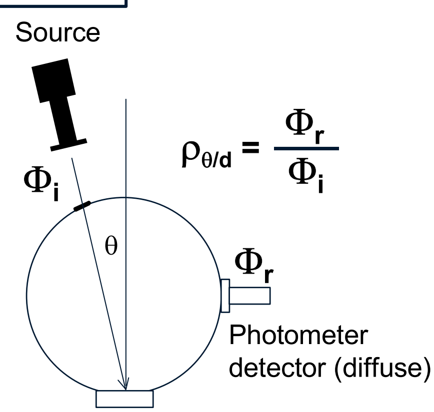
Canonical Reflection Terminology, Cont.

Helmholtz Reciprocity "Law":

$$\boxed{\beta_{d/\theta} = \rho_{\theta/d}}$$





Slide 55

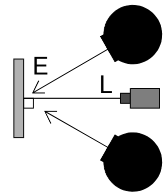
Reflection Measurements

- **Oversimplified Models — Possible Ambiguity**
  - ***"Diffuse" (Lambertian) component assumption:***

    Display surface measured as if it were matte paint.

    β = luminance factor, q = luminous coefficient,

    E = illuminance, L = observed luminance.



$$L = qE = \frac{\beta}{\pi} E$$

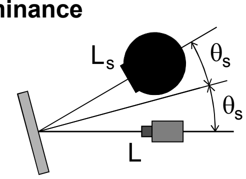
Strictly speaking this equation is for a Lambertian material: "diffuse" means scattered out of specular direction and is not limited to Lambertian materials.

  - ***Specular component assumption:***

    Display surface treated as if it were a mirror.

    ρ_s = specular reflectance, L_s = source luminance

$$L = \rho_s L_s$$



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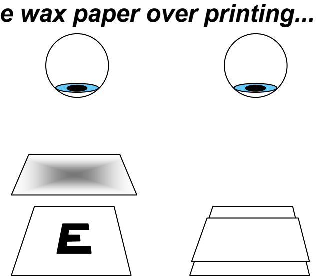
Reflection Measurements, Cont.

- **Oversimplified Model: Easy to Measure, Robust, IF OK**

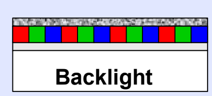
  Unfortunately, many FPDs are not well characterized by just these two components — an oversimplified model.

- **FPDs Can Permit Diffusing Surface Near Pixels**

  Like wax paper over printing...



Some FPDs allow diffusing surface close to pixels.



Intelligibility depends upon distance of strong diffusion layer from surface containing information

- **Problem: Simple Models Inadequate for All Surfaces**

  Neither Lambertian nor specular models may work!

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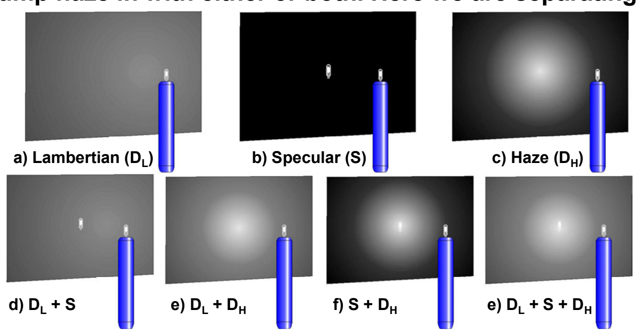
Reflection Measurements, Cont.

Three Component Reflection Model

Specular, Lambertian (Matte or "Diffuse"), Haze

Most think in terms of specular (mirror like) and diffuse (Lambertian-like) and lump haze in with either or both. Here we are separating out the three.



Haze: *Intermediate state between specular and Lambertian.*

Haze reflection is proportional to the illuminance (like Lambertian) but follows the specular direction. Often combined with other components in measurements.

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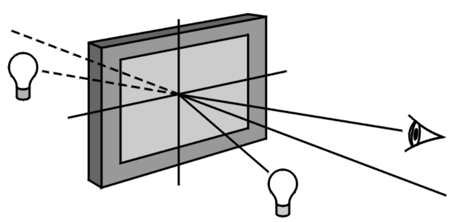
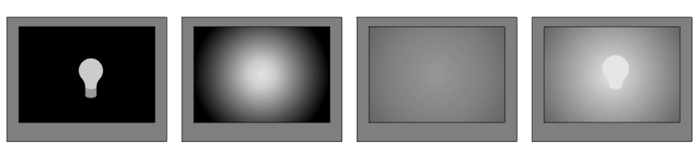
Reflection Measurements, Cont.

Three Component Reflection Model, Cont.

Specular, Lambertian, Haze

Virtual Image (if there is a specular component)





Specular Only | *Haze Only* | *Lambertian Only* | *All Three*

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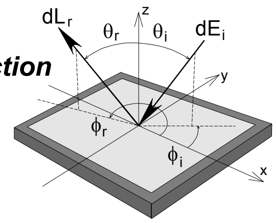
Reflection Measurements, Cont.

BRDF — Three Components:

- ***Bidirectional Reflectance Distribution Function***
- ***A generalization of L = qE.***



$$dL_r(\theta_r,\phi_r) = B(\theta_i,\phi_i,\theta_r,\phi_r;\lambda,p)\,dE_i(\theta_i,\phi_i)$$

$$B = D_L + S + D_H \qquad \begin{cases} D_L = q = \beta/\pi & \Rightarrow \text{Lambertian (diffuse)} \\ S = 2\rho_s\delta(\sin^2\theta_r - \sin^2\theta_i)\delta(\phi_r - \phi_i \pm \pi) & \Rightarrow \text{Specular} \\ D_H = H(\theta_i,\phi_i,\theta_r,\phi_r) & \Rightarrow \text{Haze (diffuse)} \end{cases}$$

$$L_r(\theta_r,\phi_r) = qE + \rho_s L_s(\theta_r,\phi_r \pm \pi) + \int_0^{2\pi}\int_0^{\pi/2} H(\theta_i,\phi_i,\theta_r,\phi_r)\underbrace{L_i(\theta_i,\phi_i)\cos(\theta_i)d\Omega}_{\text{dE, element of illuminance}}.$$

dE, element of illuminance

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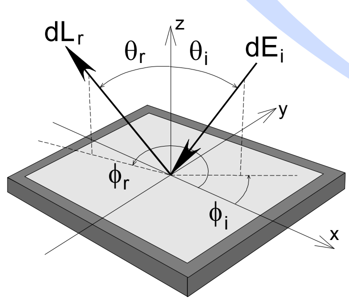
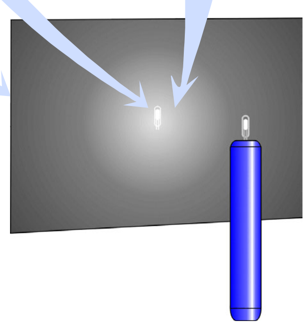
Reflection Measurements, Cont.

Observed Luminance = *Lambertian Component* + *Specular Component* + *Haze Component*

$$L_r(\theta_r,\phi_r) = qE + \rho_s L_s(\theta_r,\phi_r \pm \pi) + \int_0^{2\pi}\int_0^{\pi/2} H(\theta_i,\phi_i,\theta_r,\phi_r)L_i(\theta_i,\phi_i)\cos(\theta_i)d\Omega.$$

Background gray **Distinct image** **Fuzzy ball**





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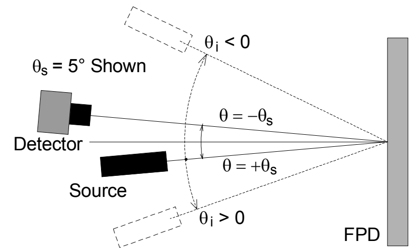
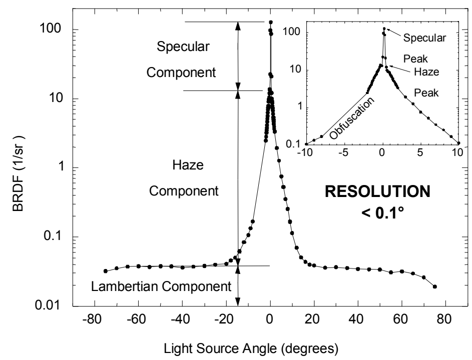
Reflection Measurements, Cont.

- **Simple BRDF**
  - ***Extremes:***
    - **Lambertian (flat)**
    - **Specular (spike)**
    - **Haze is in between.**
  - ***Haze characteristics:***
    - **Proportional to illuminance**
    - **Directed in specular direction**



SPECIALLY PREPARED SAMPLE (M + S + H)



NOTE: 3 to 5 orders of magnitude possible (or more!—your eye has no trouble seeing this range!)

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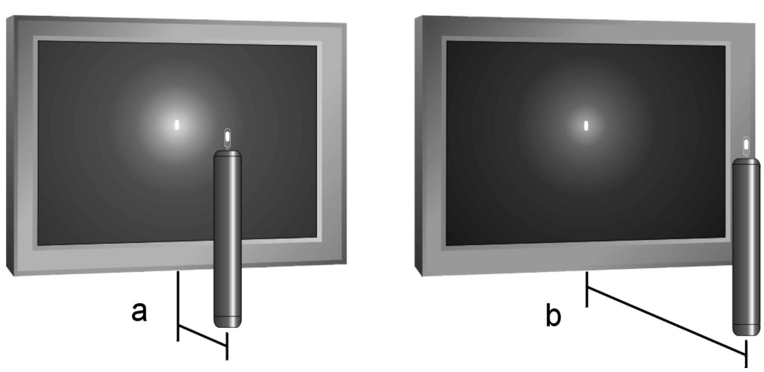
Reflection Measurements, Cont.



Like the Lambertian component, the haze is proportional to the illuminance; but like the specular component, it follows the specular direction.

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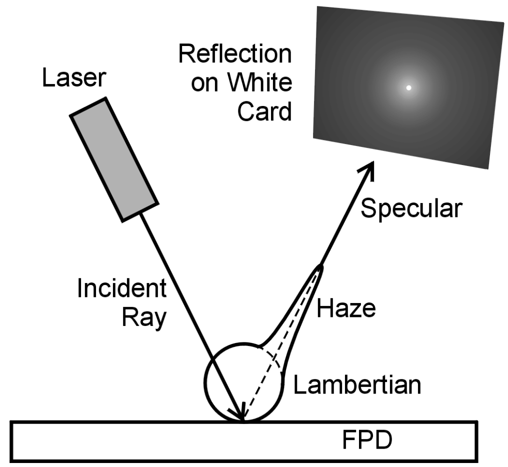
Reflection Measurements, Cont.

Reflection of laser beam onto white card gives the BRDF projected onto a plane.



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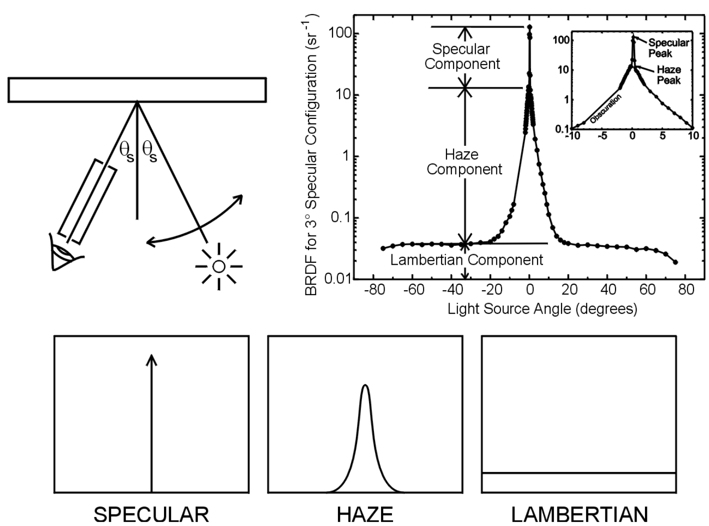
Reflection Measurements, Cont.

Three components in BRDF often seen in CRTs



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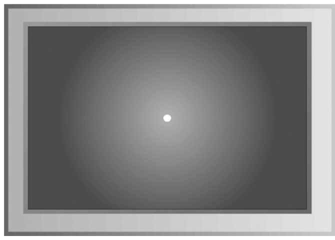
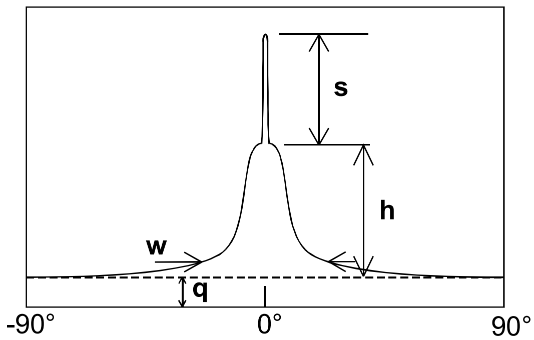
Reflection Measurements, Cont.



In the most general case, when there is a Lambertian, specular, and haze component, there are at least four parameters that are needed to specify the reflection characteristics since haze has a peak and a width (at the very least).



KEY POINT

If we only make two simple measurements or three, the problem is underdetermined and an infinite number of displays can measure the same and look different to the eye!

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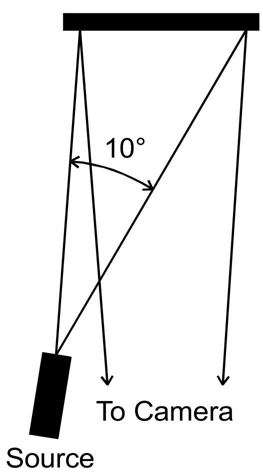
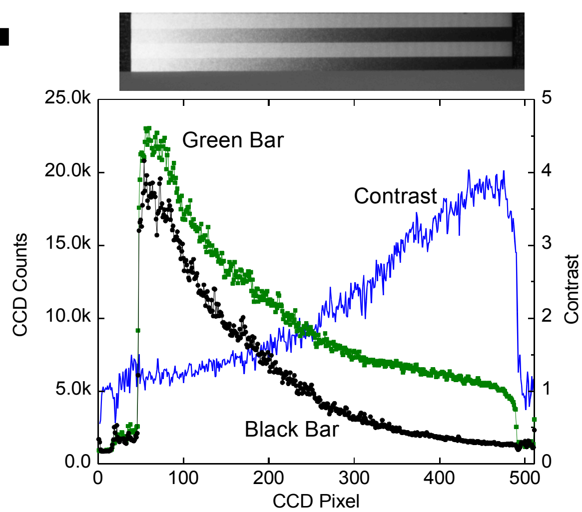
Reflection Measurements, Cont.

Haze exhibits angular sensitivity to position of source.
What contrast do we want???





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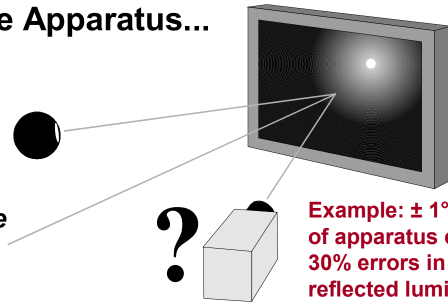
Reflection Measurements, Cont.

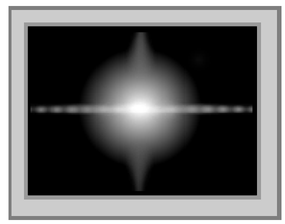
- **With Haze, Measurements Can Be Sensitive to the Geometry of the Apparatus...**
  - ***LMD distance***
  - ***Lens diameter***
  - ***Focus***
  - ***Source size***
  - ***Source distance***
  - ***…?***



Example: ± 1° misalignment of apparatus can result in 30% errors in measured reflected luminance.

- **Haze Reflection Need Not Be Symmetrical.**

  Star patterns and spikes further complicate a full characterization of reflection, accomplished only via a complete BRDF.



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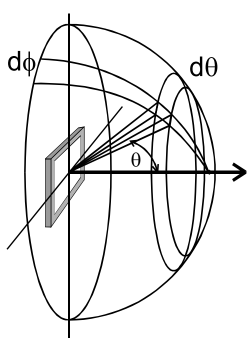
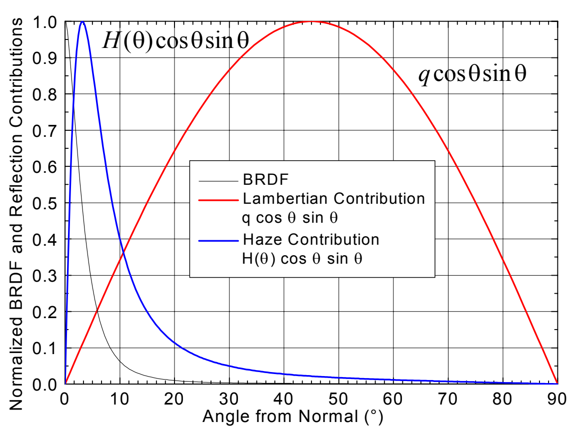
Reflection Measurements, Cont.

What is the reflection contribution (as a function of angle) from the Lambertian component compared to the haze component for a ring of light about the normal from a uniform luminance hemisphere?

$$L_R = \iint BL\cos\theta\sin\theta\, d\theta\, d\phi = \begin{cases} 2\pi qL\int\cos\theta\sin\theta\, d\theta, & \text{Lambertian} \\ 2\pi L\int H(\theta)\cos\theta\sin\theta\, d\theta, & \text{Haze} \end{cases}$$





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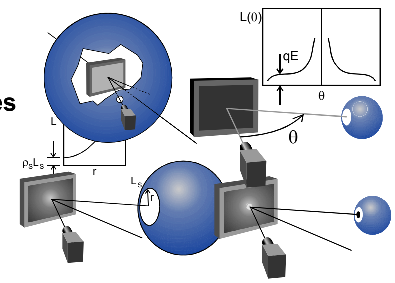
Reflection Measurements, Cont.

- **Proposed Simple Measurement Schemes:**

  Acceptable Methods Must Be...

  - **Robust:** Results not subject to small apparatus imperfections or irregularities or choice of equipment
  - **Reproducible:** Same results obtained with same displays around the world
  - **Unambiguous:** Apparatus configuration and requirements clearly presented and all important concerns made obvious



OBJECTIVE: To find the minimum set of measurements to adequately quantify reflection performance for a variety of applications.

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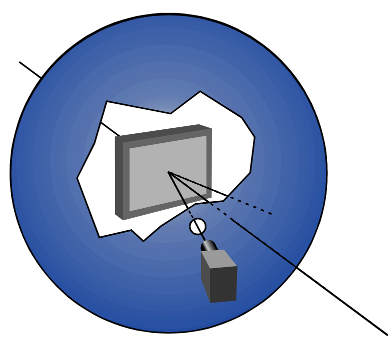
Reflection Measurements, Cont.

- **Directed Hemispherical Reflectance ($\beta_{d/8} = \rho_{8/d}$)**
  - ***A Worst-Case Situation:*** Uniform light surround with normal of display tilted approximately 8° to 10° from axis of measurement hole.
  - ***Reproducible:*** A variety of apparatus can be used to reproduce sufficiently the uniform hemispherical surround conditions.
  - ***Robust:*** Results tend to be insensitive to apparatus configuration and angular alignment.



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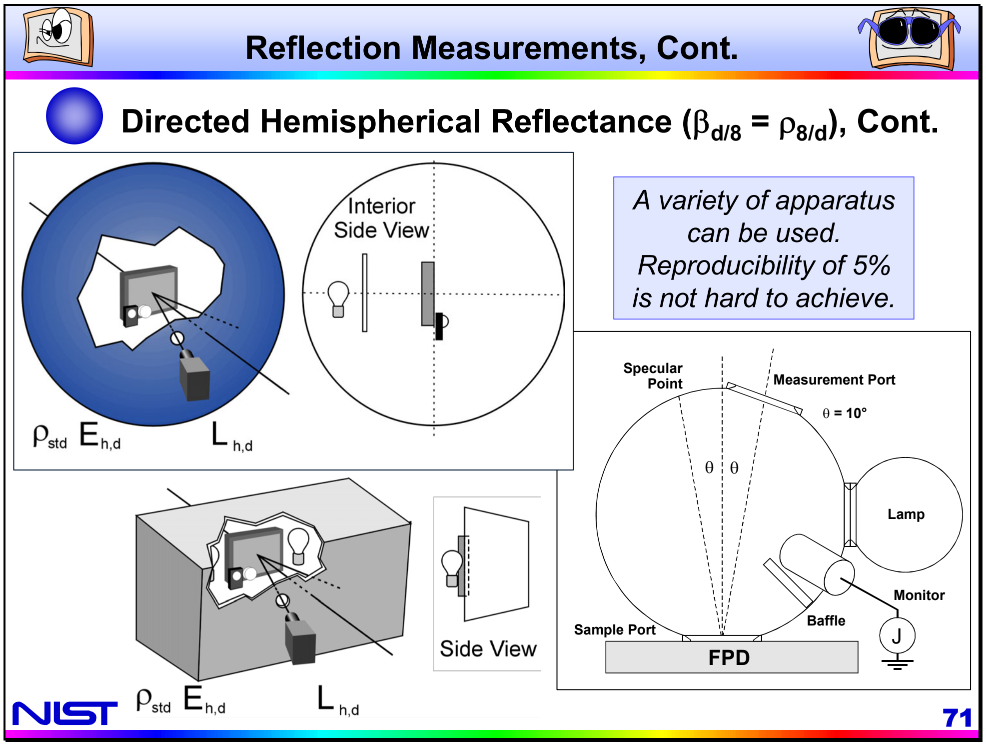

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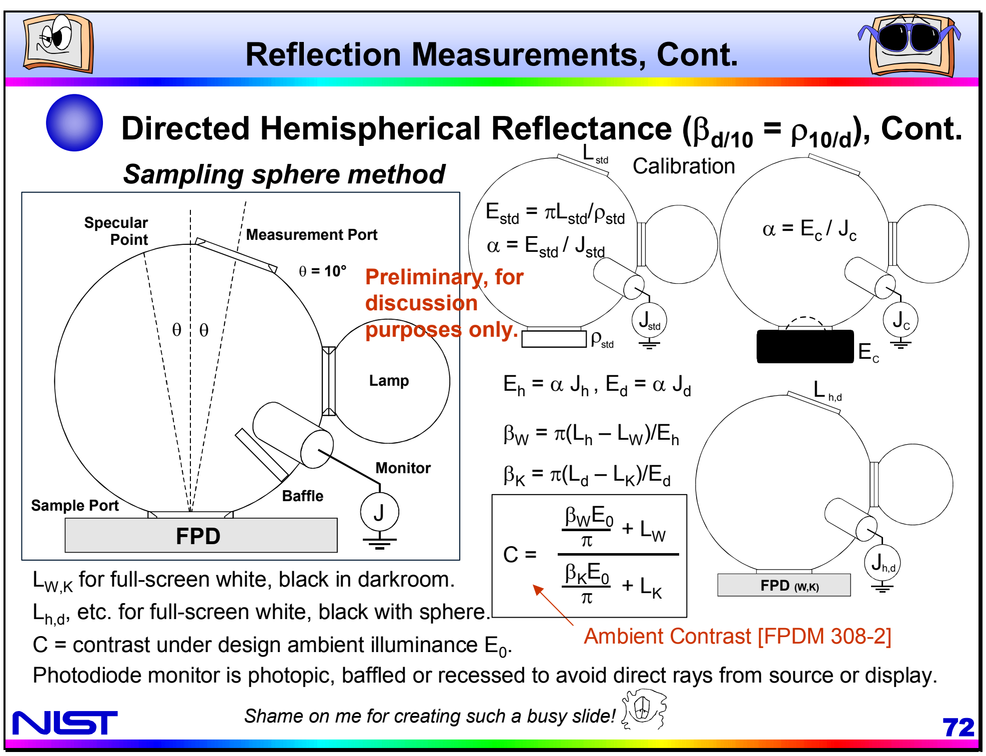

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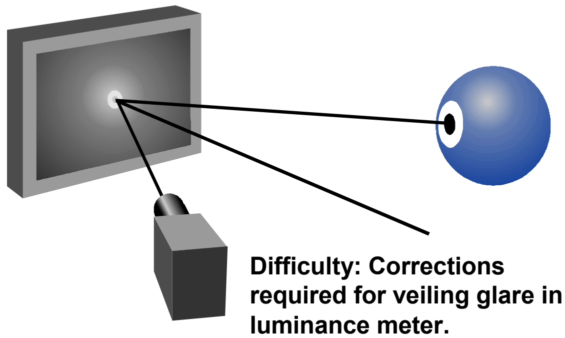
Reflection Measurements, Cont.

Annulus Measurement Separates h & ρ_s

- ***Method Under Research:*** **Method is capable of separating haze peak *h* from the specular reflectance ρ_s (producing a distinct image). Good even for determining small specular reflectances.**



Difficulty: Corrections required for veiling glare in luminance meter.

In many cases, the Lambertian component q is much smaller than the haze peak or the specular component and will be found to be only a small correction.

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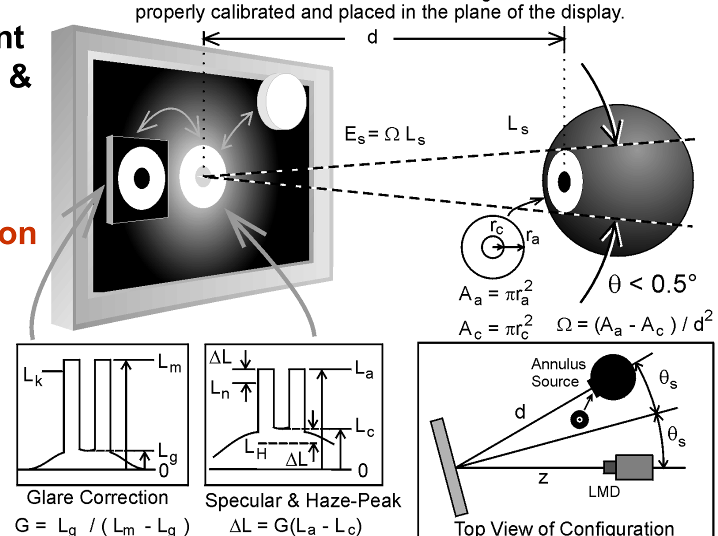
Reflection Measurements, Cont.

Annulus Measurement Separates h & ρ_s, Cont.

Preliminary, for discussion purposes only.

If a white standard is used to measure E_s, it must be properly calibrated and placed in the plane of the display.



$G = L_g / (L_m - L_g)$

$L_k = L_m / (1 + G)$

$\Delta L = G(L_a - L_c)$

$L_H = L_c - \Delta L$

$\rho_s = (L_a - L_c)/L_s \quad h = (L_H / E_s) - q$

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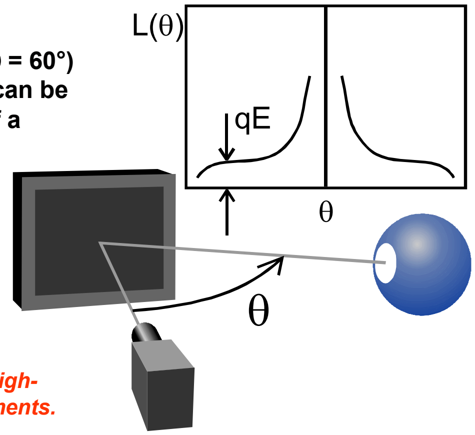
Reflection Measurements, Cont.

Simple BRDF Measurements

- ***BRDF Avoiding Complications Near Peak:*** **Simple BRDF measurements can be made avoiding the region of the specular peak.**
  - **For large angles (θ = 50° to θ = 60°) the Lambertian component can be obtained or approximated (if a nontrivial one even exists).**
  - **Provides a means of calculating the effects of isolated sources such as the sun at angles away from the specular.**



Many don't want to make high-resolution BRDF measurements.

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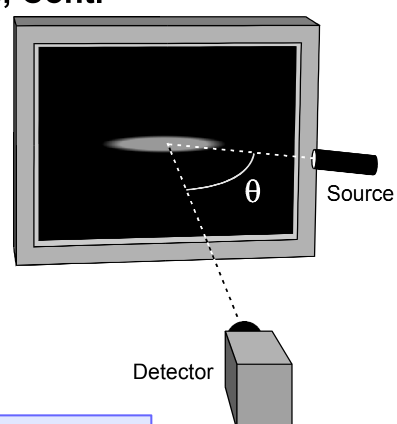
Reflection Measurements, Cont.

Simple BRDF Measurements, Cont.

Limitations on the diameter of the source, the diameter of the detector and their respective distances from the display need to be determined for the range of θ of interest. The closer θ is to the normal, the smaller these diameters need to be in order to provide an accurate large-angle BRDF measurement.



This method is most suitable for BRDFs that are symmetric about the normal.

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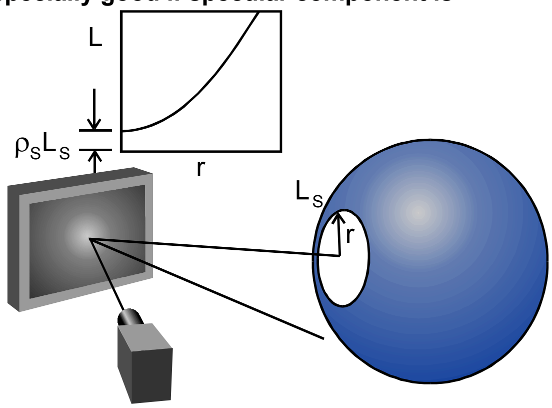
Reflection Measurements, Cont.

Variable Area Source Isolation of ρ_s

- ***Method Under Research:*** **Extrapolation to zero radius reveals specular component. Especially good if specular component is strong.**

Size of lens and distance to detector may be important for extracting any haze-peak information. Focusing on source rather than display may be required for specular component measurement.



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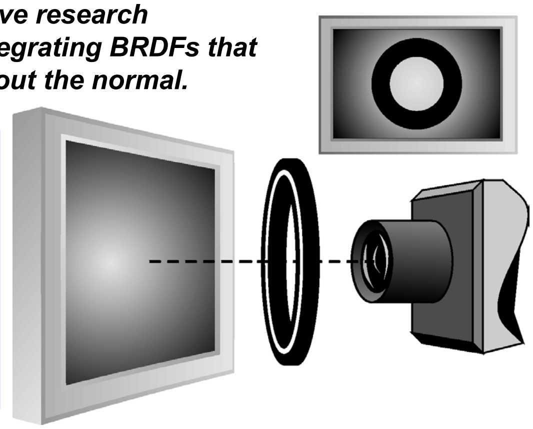
Reflection Measurements, Cont.

Measurements Using Ring Lights

Preliminary, collaborative research underway. Good for integrating BRDFs that are not symmetrical about the normal.

Whenever the haze component is present, the measurement results can become very sensitive to the geometry of the apparatus. What requirements are required to assure a reproducible measurement need to be determined.



Similar methods use fluorescent ring lights, etc.

Caution: The use of different sources having different spectral compositions can change the measurement results.

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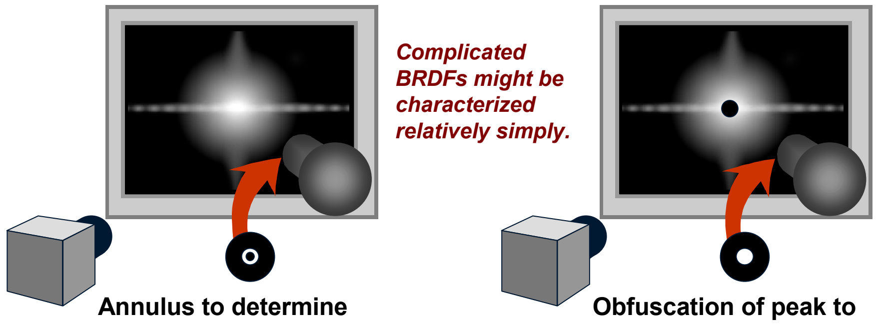
Reflection Measurements, Cont.

Array Detector 2-Dimensional Measurements

- ***Method Under Research:*** **Relationship between (x,y) coordinates on the screen to incident and reflected angles provides a BRDF characterization — uses annulus, obfuscation disk, and small aperture on source; with source near screen and small-aperture array detector (providing large depth of field).**



Annulus to determine specular reflectance and haze peak

Obfuscation of peak to reveal BRDF structure (reducing veiling glare)

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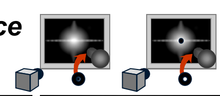
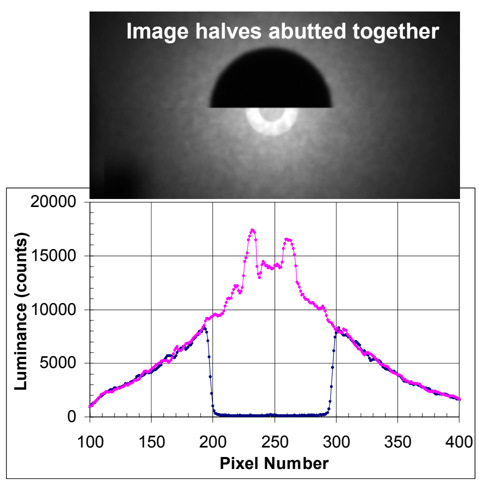
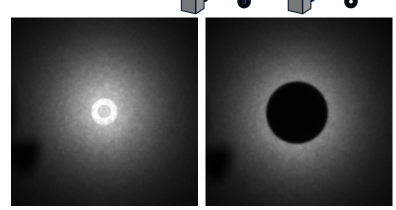
Reflection Measurements, Cont.

Array Detector 2-Dimensional Measurements, Cont.

To have both the obfuscation disk and the source in focus requires a small detector diameter.







Because the specular component is small for the sample shown, the veiling glare corruption in the wings is small. With stronger specular components we would expect to see more corruption.

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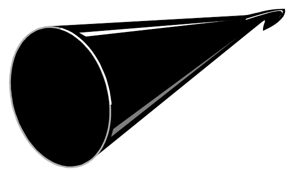
Tips and Things

Cone Light Trap

- ***Small, an absolute black, put in field of view.***
- ***Large, trap to absorb reflections off screen.***
- ***Make from gloss-black plastic.***
- ***Turn tip around or fold back on itself so there won't be a reflective cup at the end.***

If you can't find black plastic sheets that are very black (manufacturing quality varies), you might try painting a thin plastic sheet with a good high-gloss black oil-base paint from a quality paint company.



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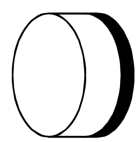
Tips and Things, Cont.

White Reflectance Standard



- ***Possible to obtain types that can be refurbished in your lab (e.g., 220 to 240 grit water-proof emery paper using circular-linear combined motion under running water).***
- ***Make sure it is sufficiently thick (some need to be 10 mm depth or more, whatever the manufacturer states is necessary). A 50 mm diameter disk may be required.***
- ***Over 99% reflectance (e.g. $\rho_{0/d}$), quasi-Lambertian… BUT watch out!!! … What kind of reflectance is this 99% value???***

CAUTION:* *These may not be Lambertian. *The reflectance (e.g., of 0.99) is obtained under specific conditions of illumination and reflected-light measurement (e.g., $\rho_{6/d}$ or $\rho_{0/d}$ —illumination 6° from normal or at normal— and measurement of diffuse reflected flux in a hemisphere). The reflectance will not necessarily be the same for all angles and all configurations!!! If you need to use it for a certain configuration (other than the configuration for which it was calibrated and related configurations) then it must be calibrated for that special configuration. We cannot necessarily use the 99% value for just any configuration we want (blindly hoping that it will be OK). An illuminance meter might be better.*

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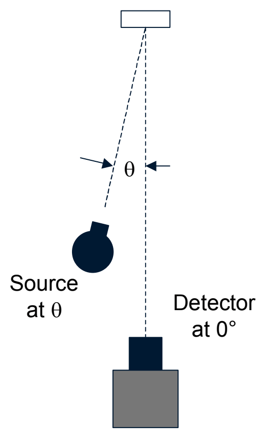
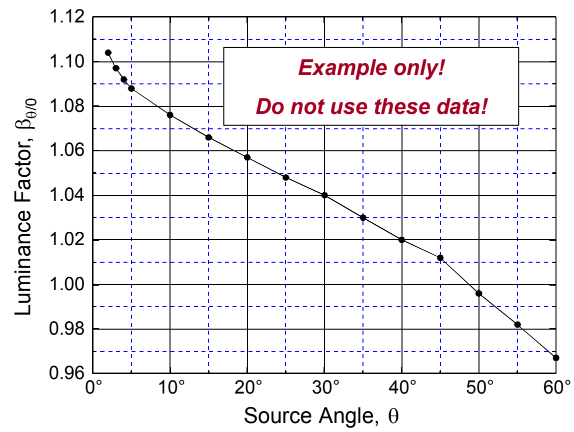
Tips and Things, Cont.

Luminance Factor of White Standard Example

Examples ONLY; don't use these results for your own purposes!!!

This shows that you cannot plop one of these in your apparatus, measure its luminance, assume a luminance factor of 0.99 and calculate the illuminance—it just isn't that simple.





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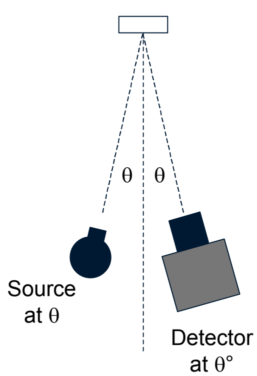
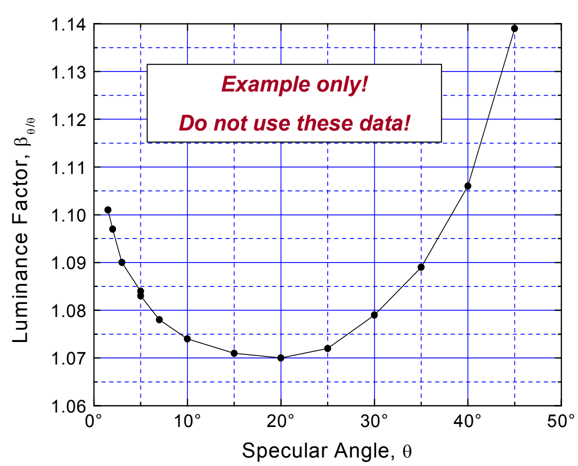
Tips and Things, Cont.

Luminance Factor of White Standard Example, Cont.

Example ONLY; don't use these results for your own purposes!!!

Specular configuration $\beta_{\theta/\theta}$ has very different characteristics from $\beta_{\theta/0}$ configuration.





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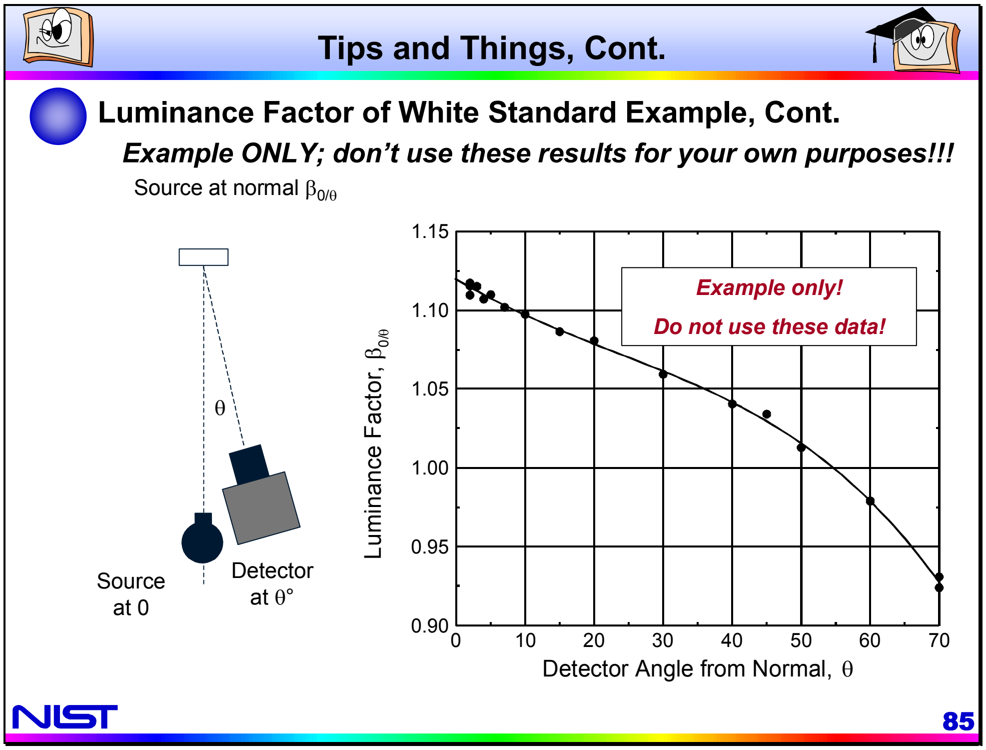

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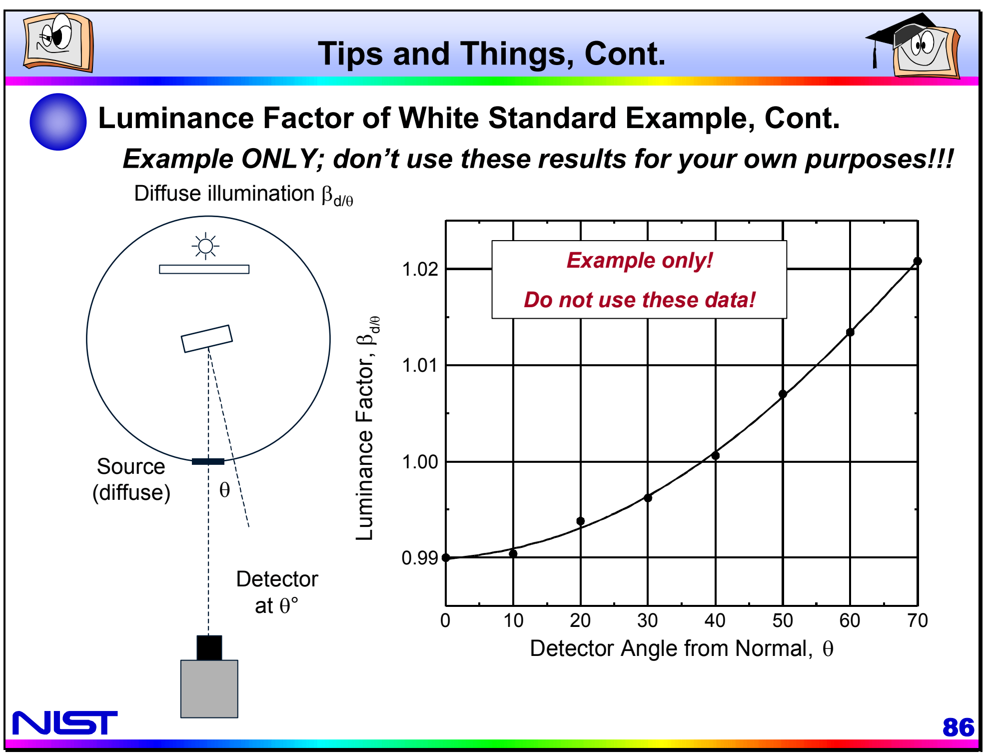

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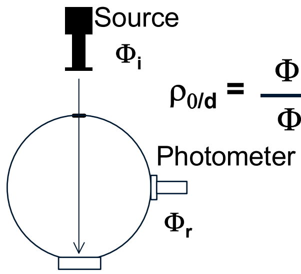
Tips and Things, Cont.

Luminance Factor of White Standard Example, Cont.

Reciprocity "law" permits only two uses of the calibrated reflectance of a reflectance standard. EXAMPLE:

Suppose the calibrated reflectance is ρ = 0.99 (or more precisely, $\rho_{d/0}$)

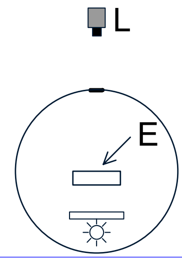


$$\rho_{0/d} = \frac{\Phi_r}{\Phi_i}$$

Then we can safely measure *E* from *L* using the luminance factor

$$\beta_{0/d} = 0.99$$

ONLY for the 0/d configuration.



$$E = \pi L / \beta_{d/0}$$

Don't use such a calibration in any other configuration unless your are certain. The basic lesson is: Geometry is often VERY important.

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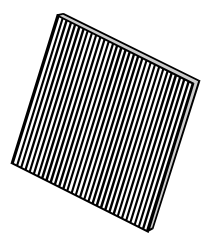
Tips and Things, Cont.

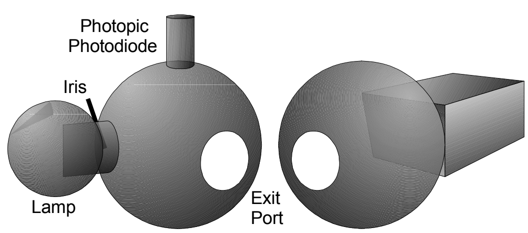
Ronchi Ruling

- ***Equal thickness black and clear grille.***
- ***High-magnification distance calibration***



Integrating Sphere Light Source

- ***Well designed, provides 1% nonuniformity or less.***
- ***Variable aperture source, no color shift.***
- ***Photopic photodiode current monitors luminance.***



Focus on exit port. Keep things away from exit port or can change luminance. Tungsten halogen source can be well-regulated. Cover exit port when not in use!

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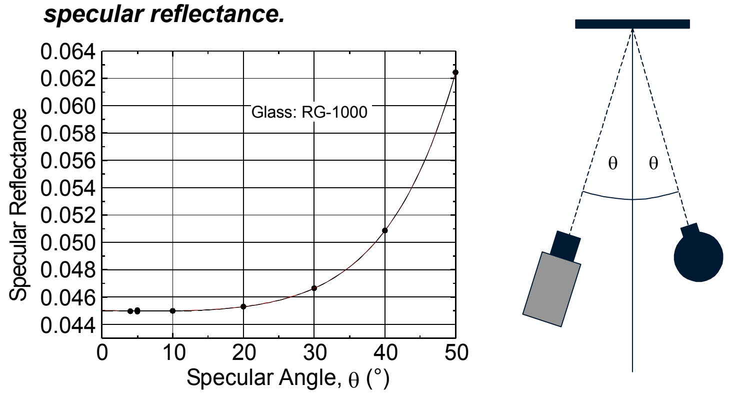
Tips and Things, Cont.

Black glass

Useful for making measurements of source in specular reflection configuration. Note slight angle dependence of specular reflectance.



Sample data only for demonstration purposes.

How we clean these can also affect the specular reflectance result ± 1 % or more.

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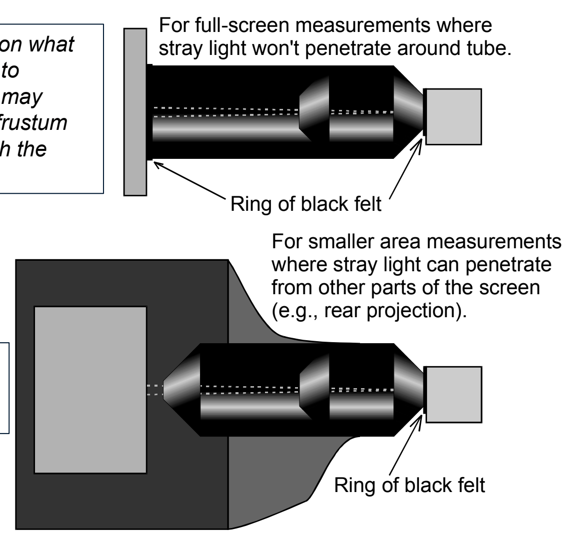
Tips and Things, Cont.

Portable darkroom using a SLET

Depending upon what you are trying to measure, you may want another frustum up front as with the SLET below.

Don't forget about a ventilation fan if using an enclosure.



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Tips and Things, Cont.

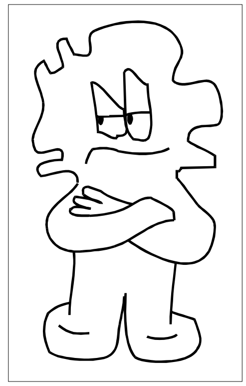
Intuition (Gut Feelings!)?

If you have a gut feeling that something is wrong, it probably is. On the other hand, if everything seems perfect, it probably isn't.

Metrology is more an attitude than procedures.

An attitude of skepticism.

(Even cynicism.)



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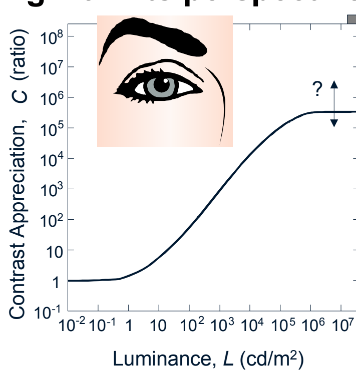
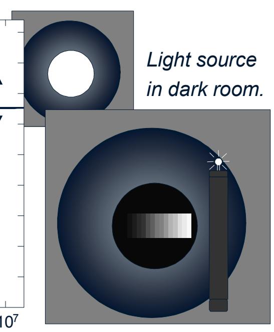
Tips and Things, Cont.

Trust your eye, look at what your instrument is seeing from its perspective.





Light source in dark room.

Proof: multilayer NDF, then add highlight.

What contrast can the eye appreciate? (Depends upon image.)

100:1 300:1 500:1 1000:1 10^4:1 10^5:1 10^6:1 10^7:1 …?

Examples: (1) Eye sees high contrast, instrument measures low contrast—trust your eye. (2) Reflections from nearby objects? (3) Light from instrument indication illumination?

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Tips and Things, Cont.

- **Diagnostics?**

  Always think in terms of diagnostics: Are you getting what you think you're getting? If you aren't sure, can you think up a way to test it out?

- **Whom do you trust?**

  Don't trust anything or anyone (as much as possible), always try to verify things you are tempted to assume, prove to yourself that everything is working properly and that you are not making inappropriate assumptions.

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Tips and Things, Cont.

- **Look for problems, be suspicious.**

  A bright display can light up a dark room, are you measuring the reflection of your white shirt or the side of a lightly-colored instrument (or wall) along with the screen color? How about equipment lights and displays in the room, do they reflect in the screen being measured? Look and see. Don't assume. If you can see it, the instrument might be affected by it.

- **Don't over document and then under document!**

  Don't spend so much time documenting untested and preliminary apparatus and data so that you can't finish the measurement—it's like polishing garbage. <u>Take the time to document thoroughly after it is working properly.</u>

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Tips and Things, Cont.

- **What Is "Good Enough"?**

  We should not compromise good metrology in favor of tradition when that tradition might be based upon inadequate metrology.

  For example, people say "Why do we have to measure it so accurately when the eye can't see it?" Well, how was that "limitation" of the eye determined? If the instrumentation used to determine the "rule" is not as good as the eye, then what can't see, the eye or the instrument? If tradition states that we only need 100:1 to adequately render a scene, how was that "rule" determined. What measurements were made? Was the instrumentation capable of an accurate measurement, how do we know? How was "adequately" defined? Be a skeptic!

- **P^{12} —Lest We Forget Working at the Bench...**

  Perpetrating paperwork, poppycock, plus protocol paralyzes promising project progress producing poor products.

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Display Standards

- **Partial Listing and Contact Information**
  - ***Notation: (see acronym list in handout)***

TC = technical committee	WG = working group
SC = subcommittee	DS = draft standard
DIS = draft international standard	CD = committee draft
PT = project team	PL = project leader

  - ***Conformance Standards***
    - **Specification of criteria to be met**
  - ***Measurement Standards***
    - **Brief descriptions of procedures—most common**
    - **Detailed descriptions of procedures & diagnostics**
  - ***See handout for listing***

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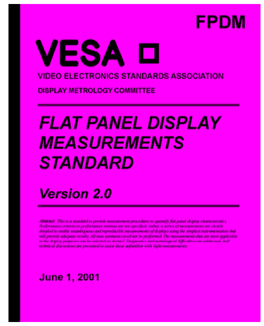
Display Standards, Cont.

Comprehensive Document Available

VESA FPDM — Flat Panel Display Measurements Standard

Features: VERSION 2.0



- Specification of good metrology for displays
- Self-contained measurement procedures
- Buffet of measurements—use what you need
- Easy to use and read
- Extensible—more will be added as needed
- Adaptable—affords a variety of equipment
- Accommodating—special needs permitted
- Metrology Section, Technical Discussions Section
- Includes diagnostics, cautions and hints
- A reasonably priced document of over 320 pages—
  VESA 408-957-9270

www.vesa.org

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